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D6.2.2

Qualitative Reasoning Model and documentation for learning about sustainable development focusing on basic biological, physical, and chemical processes related to the environment in the Danube Delta Biosphere Reserve[1]

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PP	Restricted to other programme participants (including the Commission	
RE	Restricted to a group specified by the consortium (including the Commission	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Abstract

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This deliverable presents detailed **Model documentation** for the Danube Delta Biosphere Reserve Qualitative Reasoning Model (DDBR QR Model), one of the QR Model case studies defined in the NaturNet–Redime project. The model documentation is presented in two parts: the DDBR QR model components **Implementation** (in QR workbench: Garp3) and the model **Simulation results**. The paper is structured according to Sections 6 and 7 of D6.1 *Framework for conceptual QR description of case studies*[2]. The QR model construction follows the overall principles of Sustainable Development as presented in the D6.8 *Guidelines for Sustainable Development Curriculum*[3]. Thus, the QR model will be used by end users to learn about specific conditions to be fulfilled by the modelled system (either social, economic, or environmental) in order to contribute to increased public involvement as called for in the Strategy for Sustainable Development. The model itself (constructed in Garp3 software) can be found in www.naturnet.org/NaturNet Redime Portal/Qualitative Reasoning portal/DDBR_QR Model.hgp

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Contents

Introduction

The goal of the NaturNet-Redime project is to develop educational programmes to contribute towards objectives of the European Union's Strategy for Sustainable Development (SSD; European Commission 2001). Of particular importance is the SSD objective of increasing participation in the process of making decisions that affect sustainable development by providing a tools for stakeholders, decision makers, and citizens to gain a better understanding the factors that affect SD. Part of the NaturNet-Redime project involves developing qualitative reasoning (QR) models of five case studies that explore different SD issues and scenarios, in order to support these objectives of the SSD. One of the project case studies is the Danube Delta Biosphere Reserve (DDBR).

Aquatic ecosystems are the most extensive and important natural resource of the DDBR system, both from a biodiversity and human perspective. Due to its impacts on these, **water quality**, is a central focus of concern from the point of view of the SSD. Nevertheless, water pollution is a major problem in the DDBR and has contributed to losses of biodiversity in the DDBR over the last several decades. Additionally, human populations rely on DDBR resources for fresh water and food, and so are also negatively impacted by water pollution. To make progress in reducing these negative effects, it is necessary to understand and communicate how water pollution affects biodiversity and human health in the DDBR.

The DDBR QR model was constructed to model the behaviour of DDBR aquatic ecosystem flora and fauna populations as well as human health indicators of people living in or around this area. The behaviour of these components is modelled as relating to the basic aquatic ecosystem physical, chemical and biological processes. The detailed description of Scenarios and Fragments structure, and simulation results presented in this deliverable refers to all relevant aspects concerning the basic physical, physical-chemical and biological processes within the DDBR aquatic ecosystems, focussed on chemical **water pollution processes**, their negative effects, the ways it propagates to aquatic **biological components** and, ultimately, to **human health**. The DDBR QR model comprises 17 Scenarios and 57 Model Fragments containing knowledge of structural and causal aspects of the DDBR.

The Danube Delta Biosphere Reserve Qualitative Reasoning Model Documentation

1. Implementation details

This section presents the detailed description of **Danube Delta Biosphere Reserve aquatic ecosystem Qualitative Reasoning Model** (DDBR_QR Model) ingredients **implemented** in the Qualitative Reasoning workbench: Garp3 software (Figure 1.0 Garp3 software main page).
The model ingredients are as follows:
Entity hierarchy
Attributes and values[4]
Configurations
Agent hierarchy
Assumption hierarchy
Quantities and Quantity spaces
Scenarios
Model fragments.

[4] Within the DDBR QR model there is not used "Attribute and values" feature.

Figure 1.0 Garp3 software main page.

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1.1. Entity hierarchy

Entities are the system physical components structurally related to each other by means of certain relations (configurations).

The Danube Delta Biosphere Reserve system *Entity* hierarchy, as seen in Figure 1.1, consists of three groups of entities: Human Being, Environment, and Aquatic population.

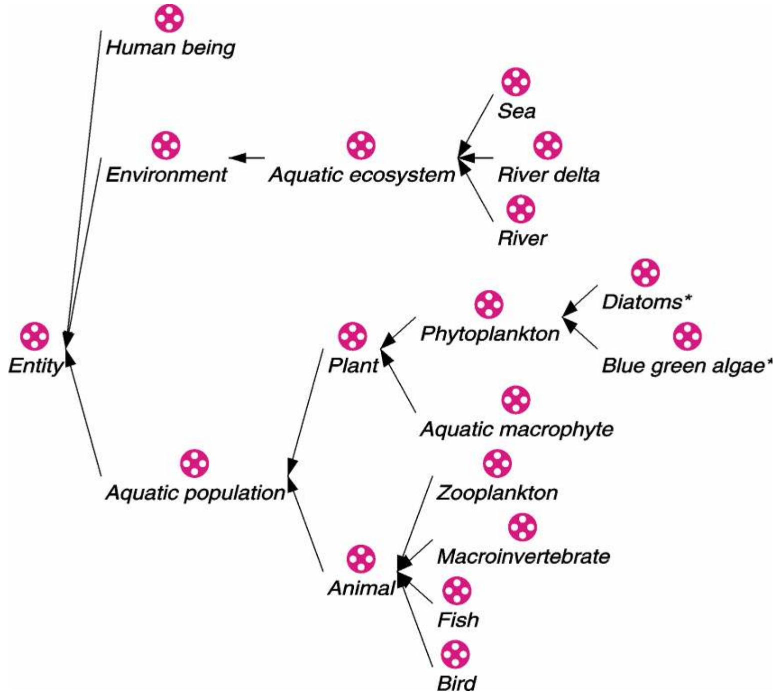


Figure 1.1 *Entity* hierarchy of the DDBR system.

I. *Human being* is part of the system, both by the DDBR inhabitants or tourists. Their health depends either directly on *Water* quality, or indirectly on *Fish* quality.

II. The "Environment" component is the *Aquatic ecosystem*.

"*Aquatic ecosystem*" consists of the following *Entities*:

1. *Sea* – is considered here to model the global behaviour of the biodiversity from the *Western Black Sea coastal zone* water which is directly influenced by the *River Delta* water quality.
2. *River* – the only Danube Delta's water resource and it's considered here from the main water pollution elements (*Heavy metals* and *Nutrients*) point of view. The *River* makes the physical connection between its *catchment area* and the River Delta.
3. *River Delta*. The DDBR QR model is focussed on this system component. *River Delta* is actually the link area between *River* and *Sea*.

III. The two *Aquatic population* groups*: Plant* and *Animal* are included in the model, along with all aquatic biological entities as follows:

1. *Plant*: *Phytoplankton,* and *Aquatic macrophyte* - primary producers groups in the framework of the Functional Feeding Group. These are food resource for primary (herbivore animal) consumers.
2. *Animal*: *Zooplankton, Macroinvertebrates, Fish,* and *Bird*. All animal are both herbivore and carnivore species.

A summary description of this system Entities is presented in Table 1.1.

Table 1.1 Danube Delta Biosphere Reserve system: Entity summary.

Entity	Super type	Description
Human being	Entity	Human being population living in or around the Danube Delta Biosphere Reserve.
Environment	Entity	Physical space where aquatic ecosystems (***River***, ***River Delta***, and ***Sea*** which this Qualitative Reasoning Model deals with) belong to.

Aquatic population	Entity	Any biological entity living in water, either plant or animal.
Aquatic ecosystem	Environment	A type of ecosystem where aquatic populations live in within a Functional Feeding Group relationship.
River	Aquatic ecosystem	Aquatic ecosystem collecting and transporting water and sediment from its hydrographic basin: the river catchment area.
River Delta	Aquatic ecosystem	Geographic area developed by the River, by flowing in through its own branches, canals, and lakes, before meeting the Sea.
Sea	Aquatic ecosystem	Geographic space where terrestrial waters flow in.
Plant	Aquatic population	This group is made of green plants (***Aquatic macrophytes*** and ***Phytoplankton***). They are autotroph organisms: able to produce themselves their energy using sunlight to convert carbon dioxide and water into sugars by photosynthesis. ***Nutrients*** are their main food resource. Plants are the primary producers in all food chains since the materials they synthesize and store are the energy sources for all other organisms.
Animal	Aquatic population	This group is made of all animals: ***Zooplankton***, ***Macroinvertebrates***, ***Fish***, ***Birds,*** and *Mammals*. They can be either herbivores or carnivores, and all are heterotroph organisms: consumers since they obtain their energy from organic substances produced by other organisms: primary producers (***Plants***).
Phytoplankton	Plant	Microscopic plant species (algae and bacteria) free-floating in the upper layer of water surface since sunlight is vital for their growth. Phytoplankton is the basis of most aquatic food chains, and one of the primary producers of the oxygen.
Aquatic macrophyte	Plant	Aquatic superior plant species: food resource for large animal species.
Diatoms	Phytoplankton	Predominant and harmless algae species division of Phytoplankton. Diatoms, as one of the primary producers, it's a significant source of food for higher trophic levels, especially for *Zooplankton*.
Blue-green algae	Phytoplankton	Bacteria species (not algae), actually named as Cyanobacteria. They have the same behaviour as any other Phytoplankton species: make photosynthesis. Most of species contain cyanotoxins in their cells. Being poisoning they "contribute" to water pollution, and to any *Aquatic population*: *Mortality*, implicitly if in High concentration in water.
Zooplankton	Animal	Microscopic species of animals inhabiting entire water column. It's food resource for larger animals, especially for fish.
Macroinvertebrate	Animal	Macroscopic animal species inhabiting both the water column and the bottom sediment (the benthos).
Fish	Animal	Vertebrate species inhabiting almost any type of aquatic ecosystem.
Bird	Animal	Vertebrate species inhabiting aquatic ecosystems or the very near areas.

1.2. Configurations

The configurations are structural relations between the modelled system entities. They define how the DDBR system entities are structurally related to each other and are implemented as described in Table 1.2.

Table 1.2 Danube Delta Biosphere Reserve aquatic ecosystems basic processes: Configuration summary

Configuration	Entity (from)	Entity (to)	Description
Drinks water from	Human being	River Delta	Specifies the link between people living inside the study area which provides their water source.
Eats	Human being	Fish	Specifies the link between people living inside the study area which provides their main food source.
Feeds on	Zooplankton	Diatoms	Specifies the feeding relationship between two aquatic species. One of them is consumer (predator) feeding on the other one (the prey).
	Macroinvertebrates	Aquatic macrophyte	
	Fish	Zooplankton	
	Bird	Fish	
Flows in	River	River Delta	Specifies direction of water flow.
	River Delta	Western Black Sea	
In catchment area of	Agriculture (Run-off of Nutrients) Agent	Danube River	Specifies the ways the Agents exert their influence on River.
	Industry (Run-off of Heavy metals) Agent	Danube River	
Lives in	Diatoms	River Delta	Specifies that these species are aquatic species.
	Blue-green algae	River Delta	

1.3. Agent hierarchy

External influences are factors that affect the system, but are external to it. These can be modelled using agents in Garp3 (Figure 1.3). The two main external influences that affect water pollution in the DDBR are:

Industry activities: source of ***Heavy metals*** running-off into Danube River;

Agriculture activities: source of ***Nutrients*** (Nitrogen and Phosphorous compounds) running-off from agricultural lands to groundwater, lakes and rivers. ***Nutrients*** as water pollutants refer only to the condition when they are in High concentration triggering the water *eutrophication* process.

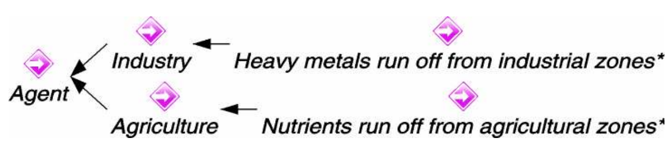


Figure 1.3 The DDBR QR model system agents hierarchy.

1.4. Assumption hierarchy

Typically, there are two types of assumptions used in the Model fragments and Scenario construction as labels, either to hide, or show a certain detail in the model. These are Simplifying or Operating assumptions.
Generally, the simplifying assumptions are used to reduce the complexity of the simulation, while the operating ones provide a certain perspective on the simulation.
The assumptions used in constructing the DDBR QR model are as shown in Figure 1.4.

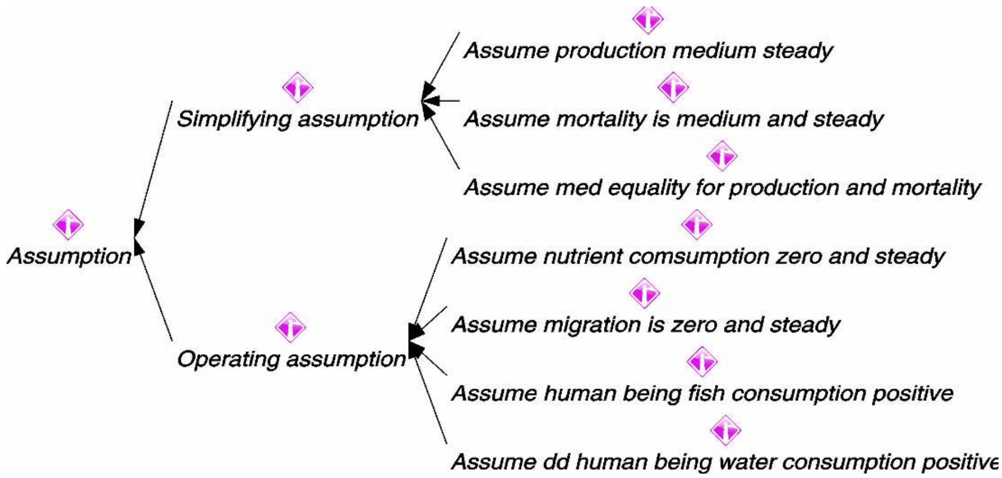


Figure 1.4 The DDBR QR model Assumption hierarchy.

1.5. Quantities and quantity spaces

Quantities used in a model represent the most important properties that characterise the modelled system entities. They are changeable features of the entities taking on qualitative values that belong to a certain Quantity space.
For the Danube Delta Biosphere Reserve system QR model, the qualitative values, Quantity spaces, and Quantities corresponding to this system Entities are as specified and described in Table 1.3.

Table 1.3 Danube Delta Biosphere Reserve aquatic ecosystems basic processes: Quantity and Quantity space summary

Quantity	Entity / Agent	Quantity space	Description
Biodiversity	Danube Delta	{Zero, Low, Medium, High}	Indicator of biological entities diversity.
Biomass	Danube Delta	{Zero, Low, Medium, High}	Total amount of a biological entity.
Cyanotoxins	Danube Delta	{Zero, Low, Critical value, High}	Concentration of Cyanotoxins in water.
Growth	Aquatic population	{Minus, Zero, Plus}	Any biological entity growth rate based on the difference between that entity Production and Mortality.
Heavy metal inflow	Danube Delta	{Zero, Low, Medium, High}	The water Heavy metals content that enters the system (water reservoir) from an upstream resource.
Heavy metal available	Danube Delta	{Zero, Low, Critical value, High}	The water Heavy metals content that remains in the water reservoir after one part from Heavy metal inflow is lost in this system.

Heavy metal bioaccumulation	Aquatic population	{Zero, Low, Medium, High}	Heavy metal consumed by adsorption by any aquatic organism body, either Plant or Animal.
Heavy metal bioaccumulation in fish muscle tissue.	Fish	{Zero, Low, Critical value, High}	Heavy metal consumed by adsorption by fish body.
Heavy metal build up rate	Danube Delta	{Minus, Zero, Plus}	The rate of building Heavy metals content that remain in the water reservoir after one part from Heavy metal inflow is lost.
Heavy metal net loss	Danube Delta	{Zero, Low, Medium, High}	Heavy metal content that is lost from the system.
Heavy metal outflow	Danube Delta	{Zero, Low, Medium, High}	The water Heavy metals content that leaves the system for a downstream water reservoir.
Heavy metal run-off	Industry (Agent)	{Zero, Low, Medium, High}	The water Heavy metals content that enters the modelled system as result of an external influence.
Human health	Human being	{Zero, Low, Medium, High}	Indicator showing how DDBR *Water pollution* influences the Human being living in or around this area.
Migration	Aquatic population	{Minus, Zero, Plus}	Either immigration or emigration of a population individuals.
Mortality	Aquatic population	{Zero, Low, Medium, High}	Population individuals disappearance either as consumed by other superior individuals or by death.
Nutrient inflow	Danube Delta	{Zero, Low, Medium, High}	The water Nutrient content that enters the system (water reservoir) from an upstream resource.
Nutrient available	Danube Delta	{Zero, Low, Critical value, High}	The water Nutrient content that remains in the water reservoir after one part from Nutrient inflow is lost in this system.
Nutrient build up rate	Danube Delta	{Minus, Zero, Plus}	The rate of building Nutrient content that remain in the water reservoir after one part from Nutrient inflow is lost.
Nutrient consumption	Danube Delta	{Zero, Low, Medium, High}	The water Nutrient content that is consumed in the system by any Plant species, since Nutrients are the main food resource for Plants.
Nutrient net loss	Danube Delta	{Zero, Low, Medium, High}	The water Nutrient content that is lost from the system.
Nutrient outflow	Danube Delta	{Zero, Low, Medium, High}	The water Nutrient content that leaves the system for a downstream water reservoir.
Nutrient run-off	Agriculture (Agent)	{Zero, Low, Medium, High}	The water Nutrient content that enters the modelled system as result of an external influence.
Pom bacterial decomposition	Danube Delta	{Zero, Low, Medium, High}	A biological process of Particulate Organic Matter (POM) decomposition which has as result the release (and recycling) of inorganic compounds (e.g. Nutrients, Heavy metals, Cyanotoxins), in water column.
Production	Aquatic population	{Zero, Low, Medium, High}	Any aquatic population growth based on food resource availability.
Temperature	Danube Delta	{Zero, Low, Medium, High}	The water physical parameter that influences chemical and biological processes.
Water pollution	Danube Delta	{Zero, Plus}	The chemical process that changes the water quality from good to bad influencing negatively the aquatic biological entities growth process and diversity (by an increase of their Mortality),

			and ultimately, the Humans whose life depends on water quality.

1.6. Model Scenarios

A scenario describes the scope of a system to be modelled. It includes the *Entities*/*Agents* involved, *Configurations* among entities/agents, *Entity*/*Agent Quantities* with initial values, and *Assumptions* (if necessary). This structure shows a possible start situation of the system from which changes in the quantity values can be triggered, describing certain behaviours of the system.

Seventeen scenarios have been developed to simulate the effects of water pollution on aquatic populations and human health. In order to model the aquatic population behaviour in the framework of the Functional Feeding Group relationships, Scenarios are constructed starting with *Plant* populations, as primary producers and ending with last consumers (*Bird*, *Macroinvertebrates*), and ultimately the *Human being*.
Figure 1.6 gives and overview of scenarios developed to explore different situation in the DDBR system. These are described in detail in the following subsections.

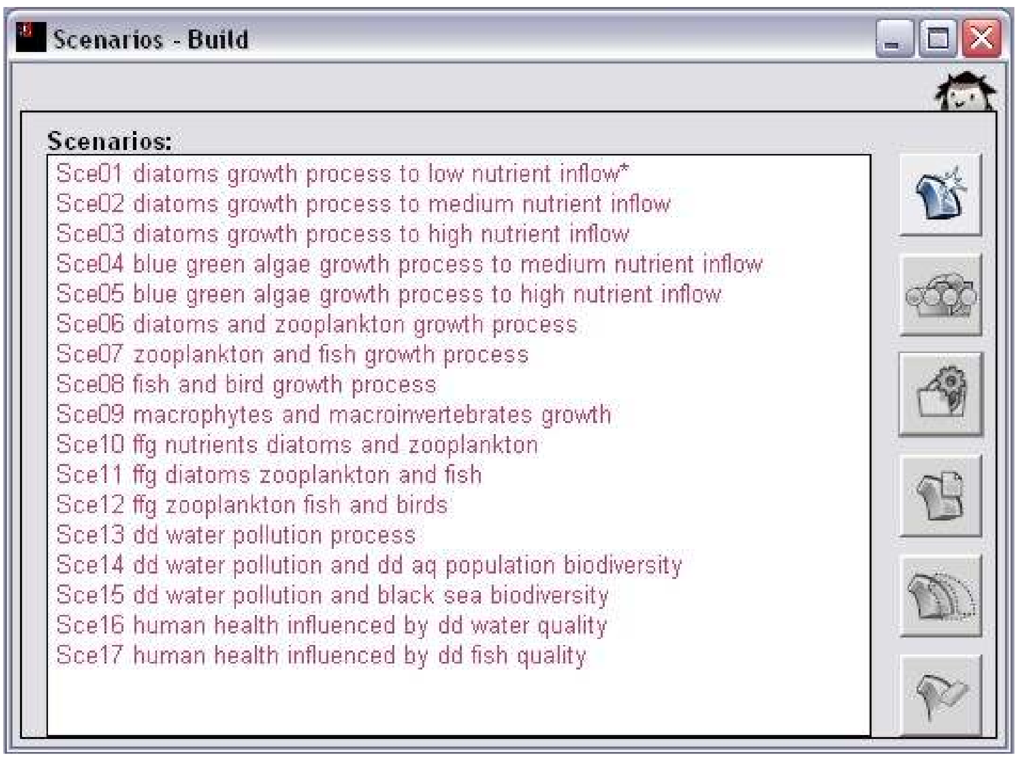


Figure 1.6 The DDBR system QR model Scenarios names.

Scenario description

This subchapter describes each Scenario (or group of Scenarios).
Scenarios are grouped as follows:

I. Scenarios concerning the aquatic *Plant* growth process for different initial values of *Nutrient inflow* in the modelled system:
   - Sce01 Diatoms growth process to low Nutrient inflow
   - Sce02 Diatoms growth process to medium Nutrient inflow
   - Sce03 Diatoms growth process to high Nutrient inflow
   - Sce04 Blue-green algae growth process to medium Nutrient inflow

- Sce05 Blue-green algae growth process to high Nutrient inflow.

II. Scenarios concerning the aquatic *Animal* growth process:
- Sce06 Diatoms and Zooplankton growth process
- Sce07 Zooplankton and Fish growth process
- Sce08 Fish and Bird growth process
- Sce09 Macrophytes and Macroinvertebrates growth process.

III. Scenarios concerning both *Plant* and *Animal* growth process in the framework of the Functional Feeding Group relationship:
- Sce10 FFG1 nutrients diatoms and zooplankton
- Sce11 FFG2 Diatoms Zooplankton and Fish
- Sce12 FFG2 Zooplankton Fish and Birds.

IV. Scenarios concerning the *Water pollution* process
- Sce13 DD (Danube Delta) Water pollution process
- Sce14 DD Water pollution and DD aquatic population biodiversity
- Sce15 DD Water pollution and Black Sea biodiversity.

V. Scenarios concerning the *Human being* behaviour from *Human health* point of view:
- Sce16 Human health affected by DD water quality
- Sce17 Human health affected by DD Fish quality.

1.6.1. Scenarios concerning the *aquatic Plant growth process*

The *Plant* growth is the only biological process in which an *Aquatic population* is crucially dependent on the availability of *Nutrients* for growth. Aquatic *Plants* consist of two different groups: *Phytoplankton* and *Aquatic macrophytes*. The most dominant species of *Phytoplankton* are: *Diatoms* (algae species) and *Blue-green algae* (Cyanobacteria species). They are separately modelled because they have different roles within an aquatic ecosystem (See Table 1.1 Danube Delta Biosphere Reserve system: Entity summary). As *Aquatic macrophytes* have the same behaviour as *Blue-green algae*, only one of these two populations was considered in constructing Scenarios, and this is *Blue-green algae*.

Taking into account the above considerations, the *Plant* growth process has been structured in five Scenarios, for three different initial values of *Nutrient inflow* and for the two aquatic *Plant* species. These Scenarios are:

Sce01 Diatoms growth process to low Nutrient inflow
Sce02 Diatoms growth process to medium Nutrient inflow
Sce03 Diatoms growth process to high Nutrient inflow
Sce04 Blue-green algae growth process to medium Nutrient inflow
Sce05 Blue-green algae growth process to high Nutrient inflow

Common features:

1. These Scenarios contain:
   1.1 The system components involved in an aquatic *Plant* growth process;
   1.2 The initial situation within the two distinguished *Phytoplankton* species (***Diatoms*** and ***Blue green algae***) growth process, based on *Nutrient available* (as main food resource for any aquatic plant species) in the system;
   1.3 Two Assumptions: *Assume migration is zero and steady* and *Assume mortality is medium and steady*.
2. Within any *Plant* growth process, the *Nutrient* has the main role, as the main food resource for aquatic Plants.
3. There are many quantities that can influence the behaviour of other quantities involved in this process. Because *Nutrient* concentration and *Temperature* have the highest influence, scenarios are restricted to investigating behaviour of different levels of these two quantities.

4. The only *Agent* participating in the *Plant* species growth process is *Agriculture* as source of *Nutrient run-off*. *Agriculture*: *Nutrient run-off* quantity has three different values: **Low**, **Medium**, or **High**. For each of these values, the derivative is **Stable**. In natural aquatic ecosystems this quantity never reaches the value Zero.
5. *Entities*: *Quantities* (Magnitude/Derivative) values included in Scenarios are:
   7.1 River delta: *Nutrient available*: Low/None; *Nutrient net loss*: Medium/None; *Pom bacterial decomposition* Medium/Steady, and *Temperature*: Zero/Increase;
   7.2 Diatoms, or *Blue green algae*: *Biomass*: Medium/None
6. The quantities generating changes in the system behaviour, as result of their associated value changes, are: *River delta*: *Nutrient available*, *Nutrient net loss*, *Temperature*, and *Diatoms*: *Biomass*.
7. The *Configurations* are: *In catchment area of*, *Flows into*, and *Lives in*. They figure the structural relationship between the system entities. (Detailed description of each configuration is presented in Table 1.2 Danube Delta Biosphere Reserve aquatic ecosystems basic processes: Configuration summary).
8. As example, the Figures 1.6.1 and 1.6.2 show the Scenarios Sce01 and Sce05 structure, for two *Agriculture*: *Nutrient run-off* quantity initial values: **Low** (Figure1.6.1) and, **High** (Figure 1.6.2), for the two *Phytoplankton* species: ***Diatoms*** and ***Blue-green algae***, respectively.
9. The two *Phytoplankton* species (*Diatoms* and *Blue-green algae*) are separately modelled to Medium and High *Nutrient inflow* because they behave differently in similar conditions. The Scenarios are Sce02, Sce03 and Sce04, Sce05 respectively.
10. Some constrains are used in constructing Scenarios, in order to reduce the simulation complexity (the number of states), such as:
    - *Assumptions*: a Simplifying assumption, *Assume migration is zero and steady* (for which the Static Model Fragment "*Assume migration is zero and steady*" is constructed); and an Operating one: *Assume mortality is medium and steady* (for which the Static MF "*Assume mortality is medium and steady*" is constructed).
    - Options selected in *Advanced quantity behaviour/*Exogenous, for a Quantity Magnitude /Derivative value, as follows: Constant/None for: *Agriculture*: *Nutrient run-off* and Medium/Steady for *River delta*: *Pom bacterial decomposition.* Options are. *Scenarios concerning the aquatic Animal growth process.*

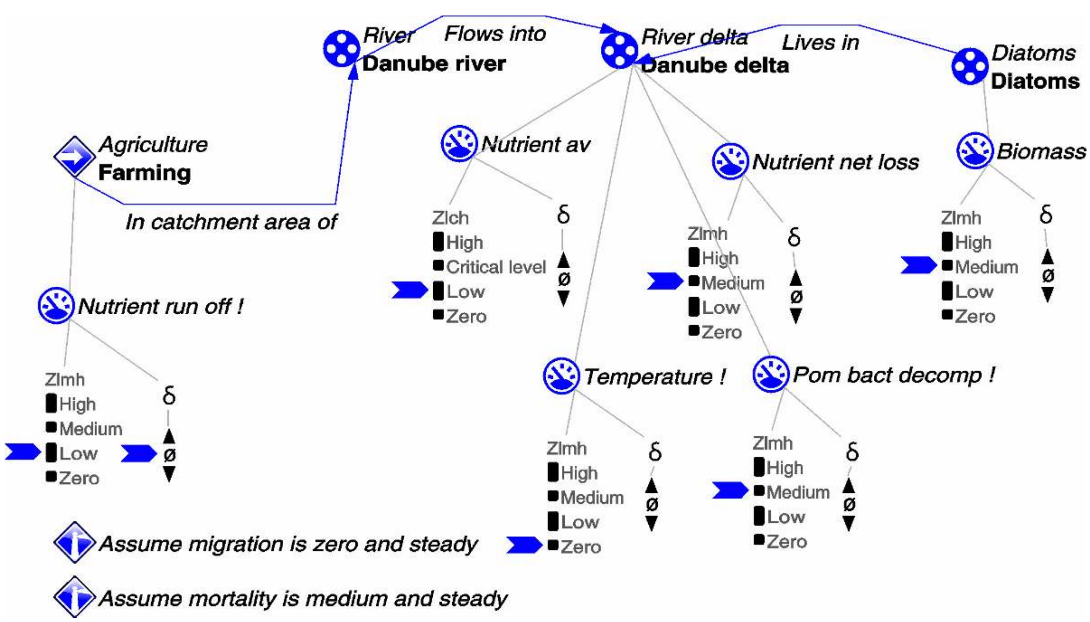


Figure 1.6.1 Sce01 Diatoms growth process to Low Nutrient inflow

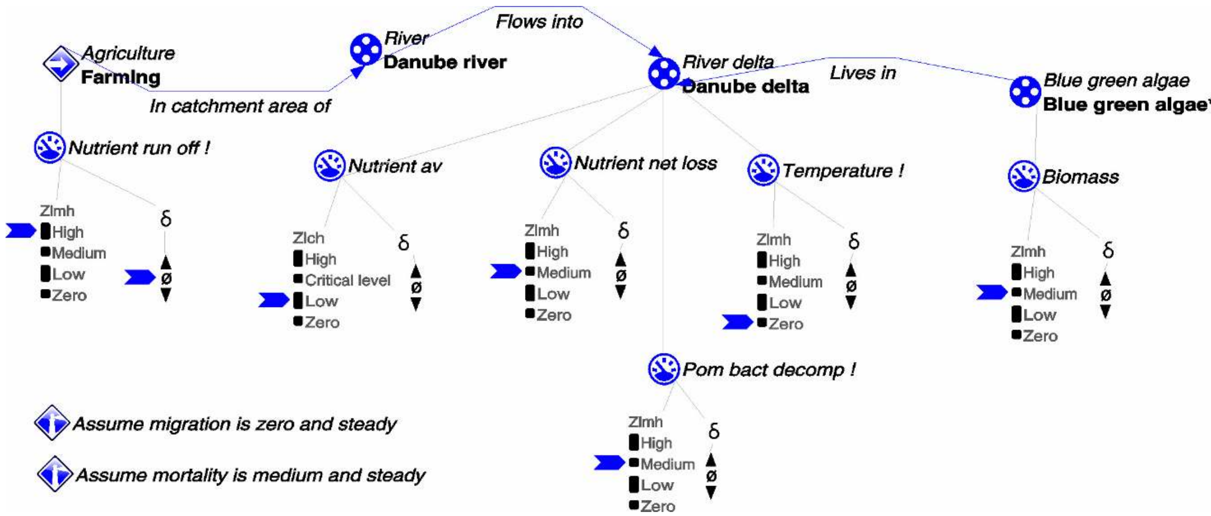


Figure 1.6.2 Sce05 Blue-green algae growth process to High Nutrient inflow

1.6.2. Scenarios concerning the *aquatic Animal growth process*

This type of Scenario concerns the biological growth process of two aquatic populations, with different role within the functional feeding group relationship: one of them is the predator, and the other one is the prey.

The Scenarios that structure this biological process refer to the following aquatic population groups:

Sce06 Diatoms and Zooplankton growth process

Sce07 Zooplankton and Fish growth process

Sce08 Fish and Bird growth process

Sce09 Macrophytes and Macroinvertebrates growth process.

Common features:

1. These Scenarios figure:
    1.1. The system components involved in an aquatic *Animal* growth process;
    1.2. The two *Aquatic Population* species: the predator species and the prey one;
    1.3. The *Configuration* is "*Feeds on*".
    1.4. Two Assumptions are introduced: *Assume migration is zero and steady* and *Assume medium equality for production and mortality*.
2. Figures 1.6.3, 1.6.4, 1.6.5, and 1.6.6 show the structure of Scenarios Sce06 – Sce09.

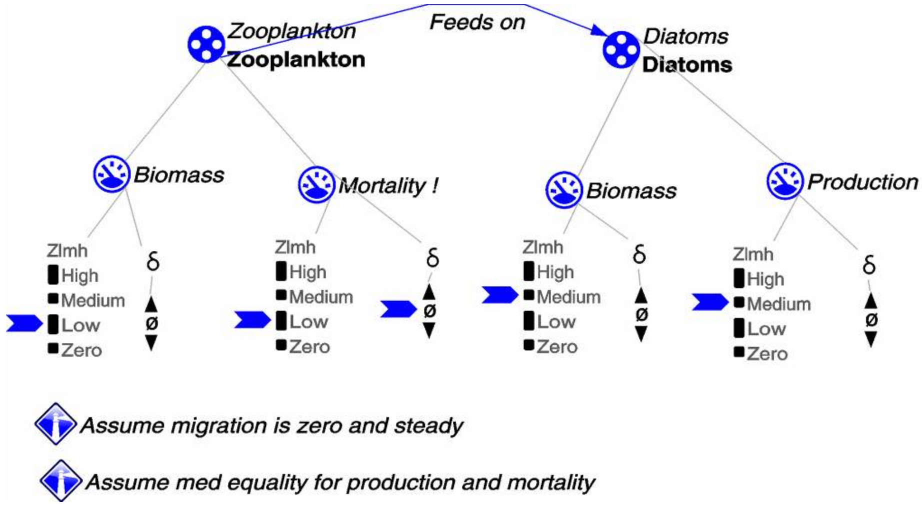


Figure 1.6.3 Sce06 Diatoms and Zooplankton growth process Scenario

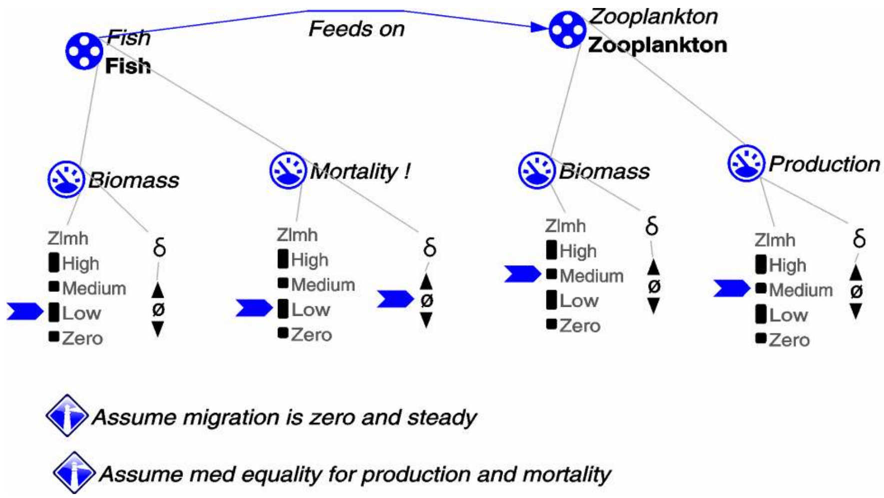


Figure 1.6.4 Sce07 Zooplankton and Fish growth process Scenario

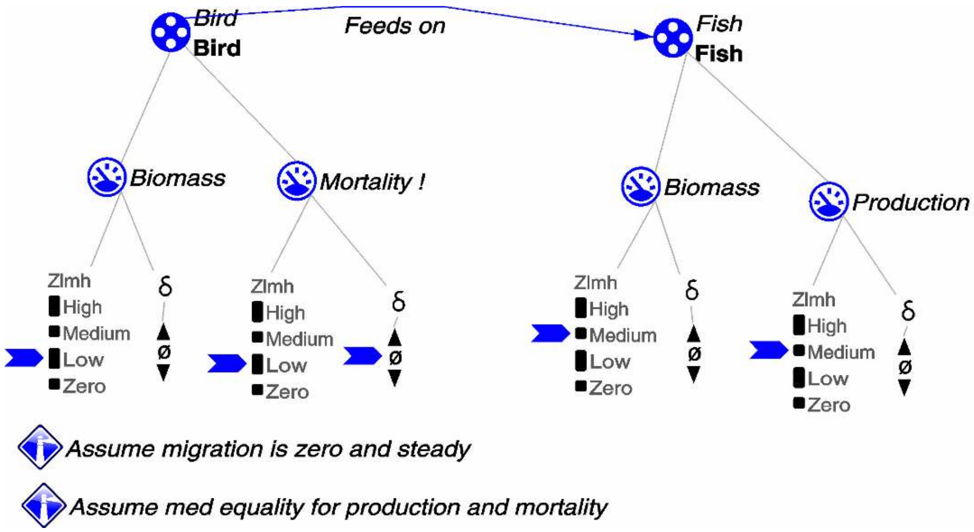


Figure 1.6.5 Sce08 Fish and Bird growth process Scenario

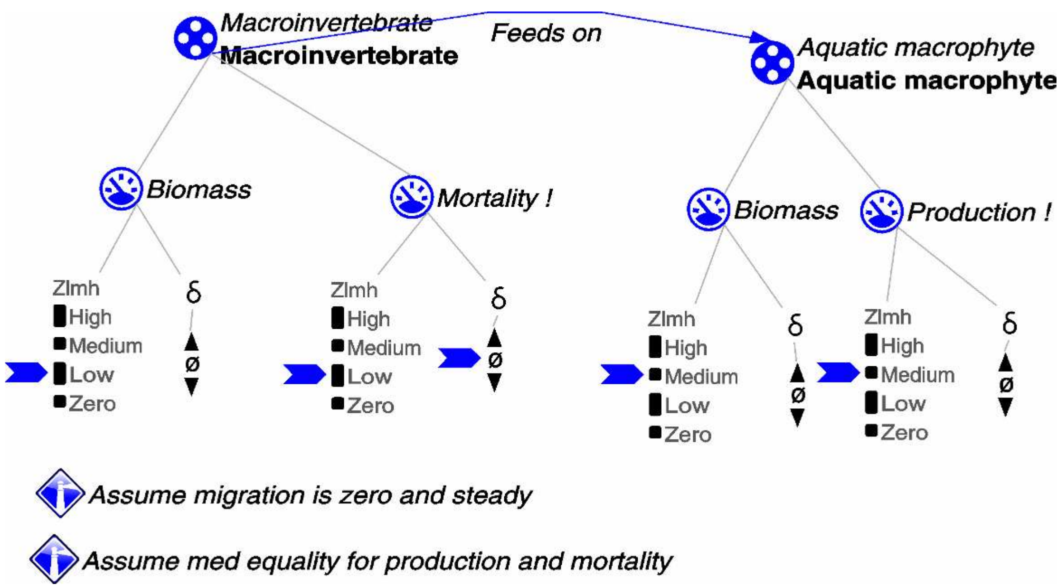


Figure 1.6.6 Sce09 Macrophytes and Macroinvertebrates growth process Scenario.

3. The initial situation of any aquatic *Animal* species (***Zooplankton***, ***Fish***, ***Bird*** and ***Macroinvertebrates***) growth process, regarding the *Quantity* values (Magnitude/Derivative) of the two *Entities* (*Aquatic populations*) involved in the process, this can be:
   3.1 For the predator species, the *Biomass*: Low/None, *Mortality*: Low/Constant;
   3.2 For the prey species, the *Biomass*: Medium/None, the *Production*: Medium /Steady
4. Within any *Animal* growth process, as there are Functional Feeding Group relationships among species, each *Animal* species can be both predator and prey.
5. The *Configuration*: *Feeds on* figures the functional feeding relationship between the two entities involved in the growth process.

1.6.3. Scenarios concerning both *Plant and Animal growth process*

These Scenarios concern the functional feeding relationships of a group of three *Aquatic Populations* with different roles, as follows: the first is the predator, the last one is the prey, and the middle one is both predator and prey.
First Scenario (Sce10) is an exception of this rule as one of the three Entities is not an aquatic biological entity, but physical part of the Environment, River Delta, where aquatic populations live. It provides the main food resource (*Nutrients*), for primary producers (*Diatoms*) within the functional feeding group (FFG).
The Scenarios structuring this biological process refer to the following *Aquatic Population* groups:
Sce10 FFG diatoms and zooplankton
Sce11 FFG Diatoms Zooplankton and Fish
Sce12 FFG Zooplankton Fish and Birds.

Common features:

1. These Scenarios figure:
   1.1 The system components involved in a group of three *Aquatic Populations* growth process;
   1.2 The Scenario's *Entities* are the three *Aquatic Populations*, excepting for the first Scenario where one Entity is a physical part of Environment (*River Delta*).
   1.3 The *Configuration* between two populations is "*Feeds on*" and "*Lives in*" between *Diatoms* (Plants as primary producers) and *River Delta*.
   1.4 Two Assumptions are included: *Assume migration is zero and steady* and *Assume medium equality for production and mortality*.
2. The *Configuration*: *Feeds on* figures the functional feeding relationship between two entities involved in their growth process.

3. Figures 1.6.7, 1.6.8, and 1.6.9 show the structure of Scenarios: Sce10 FFG nutrients diatoms and zooplankton, Sce11 FFG Diatoms Zooplankton and Fish, and Sce12 FFG Zooplankton Fish and Birds.

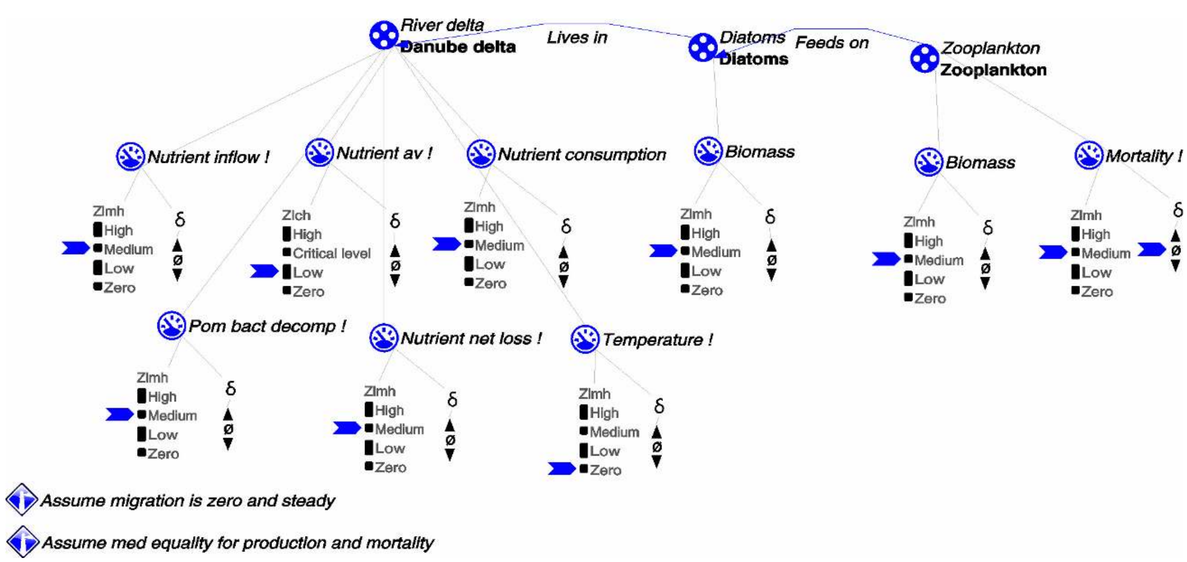


Figure 1.6.7 Sce10 FFG nutrients diatoms and zooplankton Scenario

4. The initial situation of the growth process *of Aquatic Populations* belonging to the Functional Feeding Group ***Diatoms*** and ***Zooplankton*** (Figure 1.6.7), regarding the *Quantity* values (Magnitude/Derivative) of the three *Entities:*

4.1 For *River delta*: *Nutrient inflow*: Medium/Increase; *Nutrient available*: Low/Increase; *Nutrient consumption*: Medium/None; *Nutrient net loss*: Medium/Increase; *Pom bacterial decomposition*: Medium/Steady; *Temperature*: Zero/Increase.

4.2 For the predator species, the *Zooplankton: Biomass:* Medium/None, and the *Mortality:* Medium/ Steady;

4.3 For the prey species, the *Diatoms: Biomass:* Medium/None.

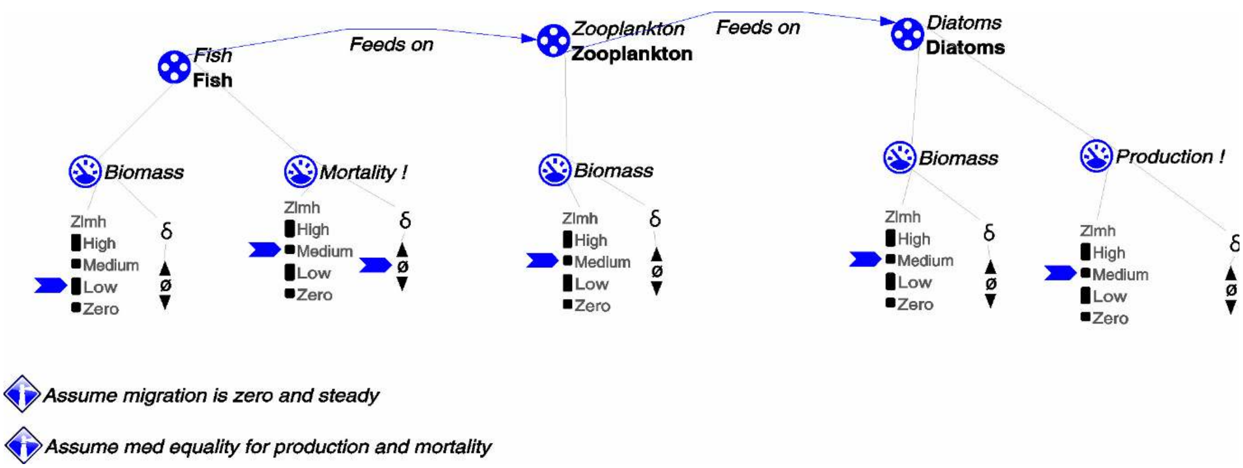


Figure 1.6.8 Sce11 FFG Diatoms Zooplankton and Fish Scenario

5. The initial situation of the growth process *of Aquatic Populations* belonging to the Functional Feeding Group ***Diatoms, Zooplankton,*** and ***Fish*** (Figure 1.6..8), regarding the *Quantity* values (Magnitude/ Derivative) of the three *Entities:*

5.1 For the predator species, the *Fish*: *Biomass*: Low/None, and the *Mortality*: Medium/ Constant/None;

5.2 For the prey/predator species, the *Zooplankton*: *Biomass*: Medium/None;

5.3 For the prey species, the *Diatoms*: *Biomass*: Medium/None, and *Production*: Medium/Steady.

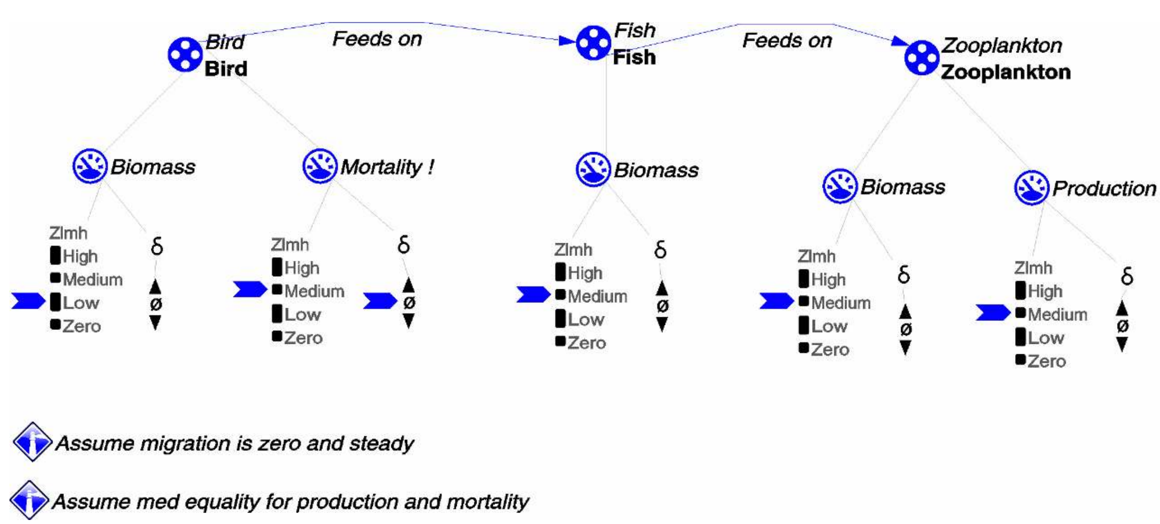


Figure 1.6.9 Sce12 FFG Zooplankton Fish and Birds Scenario

6. The initial situation of the growth process *of Aquatic Populations* belonging to the Functional Feeding Group ***Zooplankton***, ***Fish***, and ***Birds*** (Figure 1.6.9), regarding the *Quantity* values (Magnitude/ Derivative) of the three *Entities:*

6.1 For the predator species, the *Bird*: *Biomass*: Low/None, and the *Mortality*: Medium/Constant/None;
6.2 For the prey/predator species, the *Fish*: *Biomass*: Medium/None;
6.3 For the prey species, the *Zooplankton*: *Biomass*: Medium/None, and *Production*: Medium/Steady.

1.6.4. Scenarios concerning the *Water pollution process*

These Scenarios concern the modelled system's components participating in the chemical process of *Water pollution* and *Aquatic populations* affected negatively by this process, and the *Configurations* among components, as follows:

1. The two system's *Agents: Agriculture* and *Industry*, developed "*In catchment area of*" the *River*, and participating in the system *Water pollution* with *Nutrient run-off*, and *Heavy metals run-off*, respectively;
2. The *River*, that "*Flows into*" its own *River Delta*, after collecting and transporting the pollutants, mainly *Nutrients* and *Heavy metals*, from its catchmnet area;
3. The *River Delta* system's inner components: *Nutrients*, *Heavy metals*, and *Cyanotoxins*.
4. The *River Delta* that "*Flows into*" *Western Black Sea*, affecting negatively the coastal zone waters *Biodiversity*.

The Scenarios structuring this process are:
Sce13 DD Water pollution process
Sce14 DD Water pollution and dd aquatic biodiversity
Sce15 DD Water pollution and Black Sea biodiversity
Figures 1.6.10, 1.6.11, and 1.6.12 show the structure of Scenarios listed above.

5. The possible initial situation of the Danube Delta Water pollution process (Figure 1.6.10), regarding the *Quantity* values (Magnitude/ Derivative) of the two *Agents* and the modelled system's *Entities*, can be:

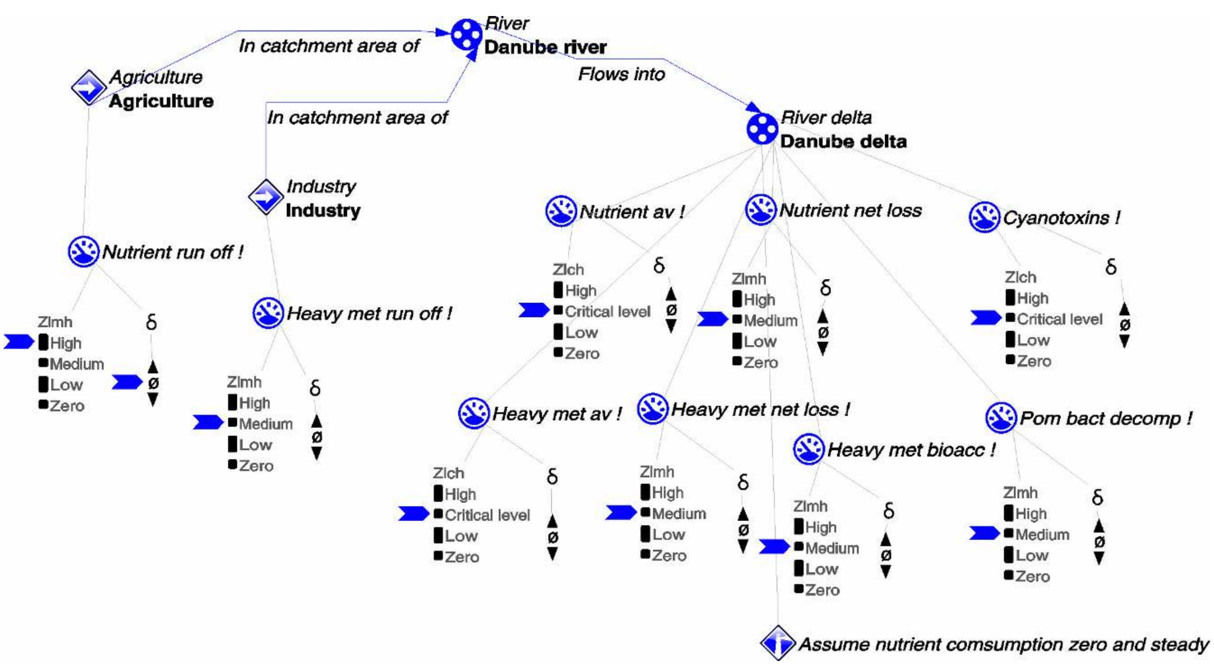


Figure 1.6.10 Sce13 Danube Delta Water pollution process Scenario.

5.1 *Agriculture Agent*: *Nutrient run-off*: High/Constant/None. The only value for this Quantity, when involved in water pollution process, is considered as High, because for values lower than High it has the main food resource role for any aquatic *Plant* species.
5.2 *Industry Agent*: *Heavy metals run-off*: Medium/Increase.
5.3 *River Delta*: *Nutrient available*, *Heavy metals available*, *Heavy metals net l*oss, *Heavy metals bioaccumulated* ("consumed" by any aquatic organism), *Cyanotoxins*, and *Pom bacterial decomposition*: Medium/Increase; and *Nutrient net loss*: Medium/None.

The *Configurations* used in Scenario structure are: *In catchment area of*, and *Flows into.*
A Simplifying Assumption is introduced in this Scenario: "*Assume nutrient consumption zero and steady*".

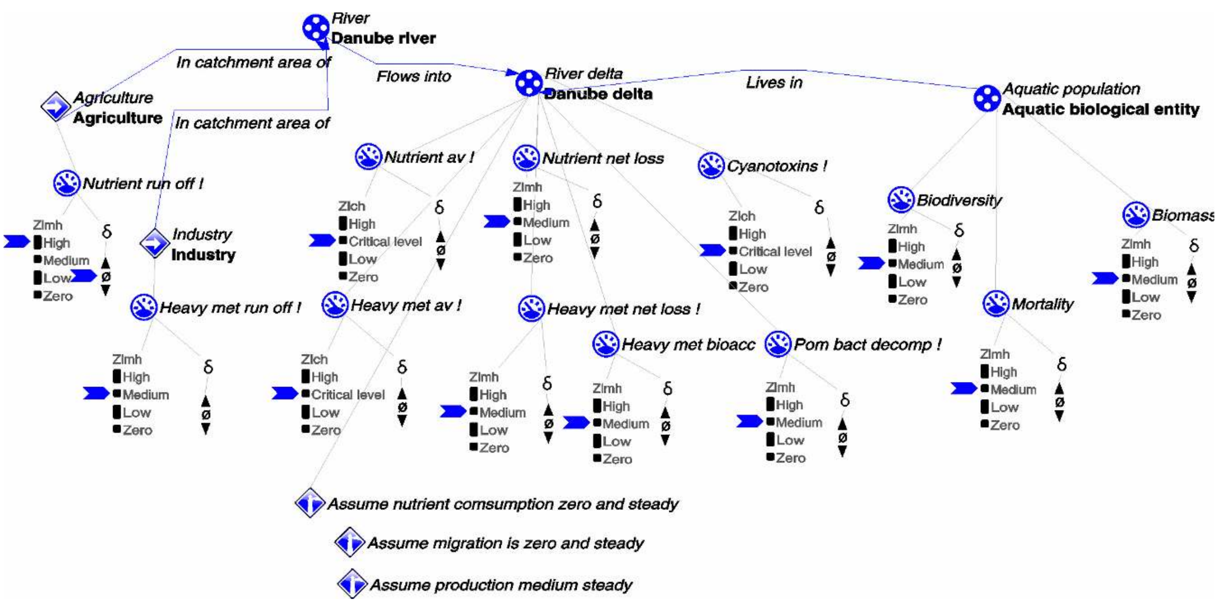


Figure 1.6.11 Sce14 DD Water pollution and dd aquatic biodiversity Scenario.

The possible initial situation of the Danube Delta Water pollution and dd aquatic biodiversity (Figure 1.6.11), is the same with the Danube Delta Water pollution process (Figure 1.6.10), described in the previous subsection (5/5.1; 5.2, and 5.3), excepting one more *Entity* added in this Scenario, *Aquatic population*, and two more Assumptions: *Assume migration is zero and steady*, and *Assume production* (of Aquatic population) *medium steady*.
The quantity initial values for *Aquatic population*: *Biomass*, *Biodiversity*, and *Mortality*: Medium/None.

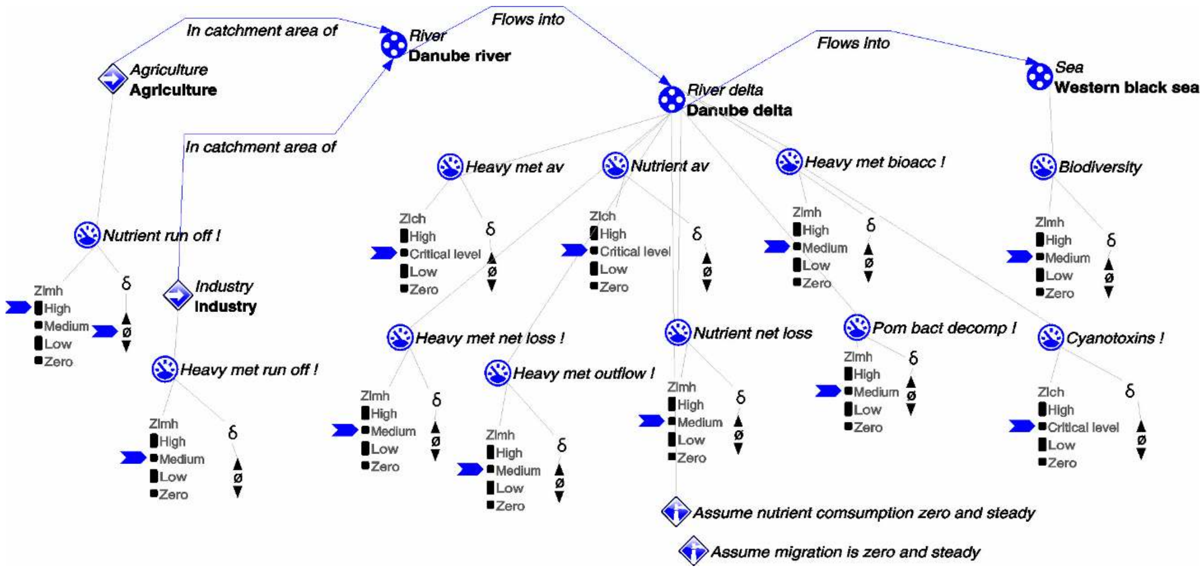


Figure 1.6.12 Sce15 DD Water pollution and Black Sea biodiversity Scenario.

The possible initial situation of the Danube Delta Water pollution and Black Sea biodiversity (Figure 1.6.12), is the same with the Danube Delta Water pollution process (Figure 1.6.10), described in the previous subsection (5/5.1; 5.2, and 5.3), excepting one more *Entity* added in this Scenario, *Sea*/*Western Black Sea*, and one more Assumptions: *Assume migration is zero and steady*.
The quantity initial values for *Sea/Western Black Sea*: *Biodiversity:* Medium/None.

1.6.5. Scenarios concerning the *Human being health*

These Scenarios structure the modelled system's components participating in the Human being health (affected negatively both directly by the *Water pollution process*, and indirectly by the *Fish* pollution process as result of *Heavy metals bioaccumulation in Fish muscle tissue*) and the *Configurations* between components, as follows:

1. The two system's Entities: Human being and River Delta, the configuration "Drinks water from" and two Assumptions: "Assume DD Human being water consumption positive", and "Assume nutrient consumption zero and steady (Figure 1.6.13 Sce16 Human health affected by dd water quality).

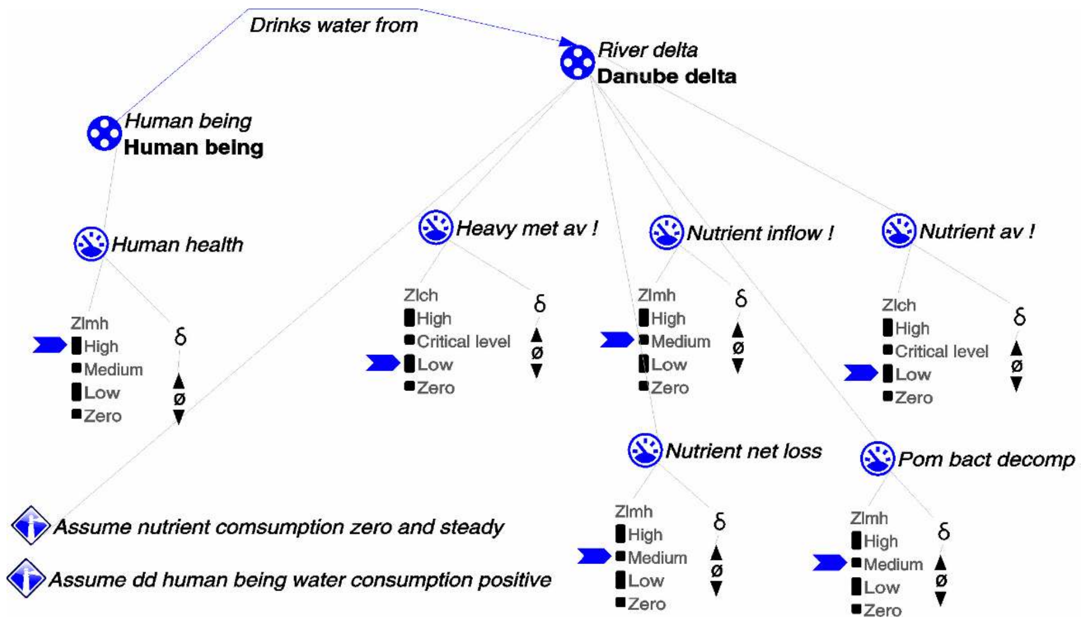


Figure 1.6.13 Sce16 Human health affected by dd water quality

2. The possible initial situation of the Human health behaviour, regarding the *Quantity* values (Magnitude/ Derivative) of the two *Entities*, can be:

2.1 *Human being*: *Human health*: High/None;

2.2 *River Delta*: *Heavy metals available*: Low/Increase; *Nutrient inflow*: Medium/Steady; *Nutrient available*: Low/Increase; *Nutrient net loss*: Medium/None; *Pom bacterial decomposition*: Medium/Steady.

3. The two system's Entities: Human being and Fish, the configuration "Eats" and three Assumptions: "Assume Human being fish consumption positive", "Assume migration (of Fish population) is zero and steady", and "Assume mortality (of Fish population) is medium and steady" (Figure 1.6.14 Sce17 Human health affected by dd fish quality).

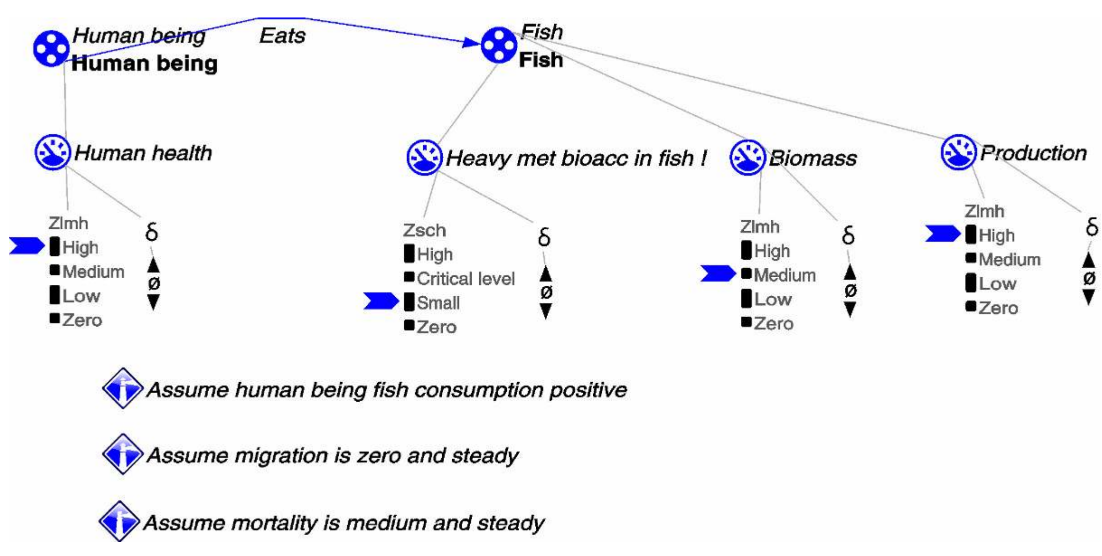


Figure 1.6.14 Sce17 Human health affected by dd fish quality.

4. The possible initial situation of the Human health behaviour, regarding the *Quantity* values (Magnitude/ Derivative) of the two *Entities*, can be:
   4.1 *Human being*: *Human health*: High/None;
   4.2 *Fish*: *Heavy metals bioaccumulation in fish* (muscle tissue): Small/Increase; *Biomass*: Medium/None; *Production*: High/None.

1.7. Model Fragments

1.7.1. Static Model Fragments

The Static MFs constructed to capture behavioural knowledge about the DDBR aquatic ecosystems components are named as shown in Figure 1.7.

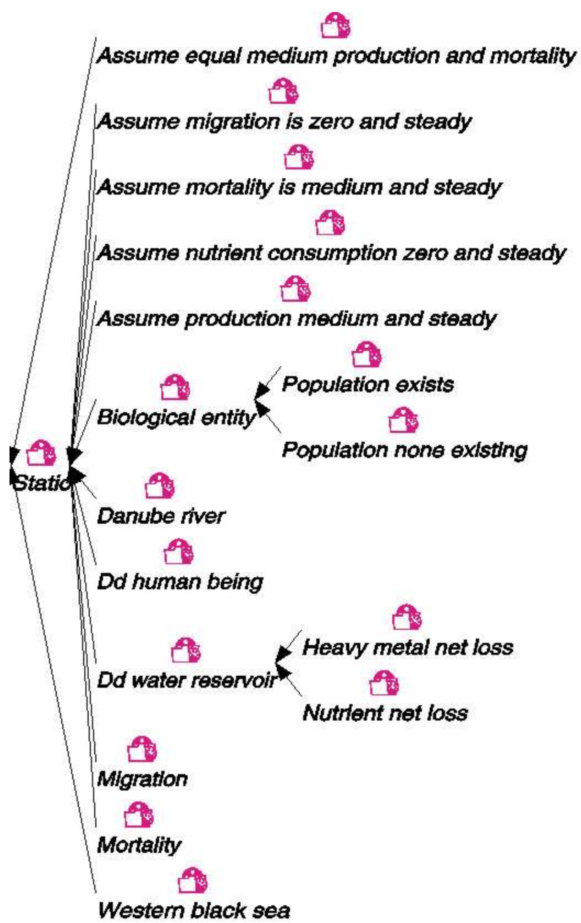


Figure 1.7 The Danube Delta Biosphere Reserve QR Model Static Model Fragments.

The MFs defining the system's behavioural features related to aquatic biological entities:

5. Biological entity: a MF (Figure 1.7.1. Biological entity Static MF) containing as condition (in red colour) the entity Aquatic biological entity*,* the Entity Instance *of Aquatic population.* This entity has as consequence (in blue colour) the quantity *Biomass*.

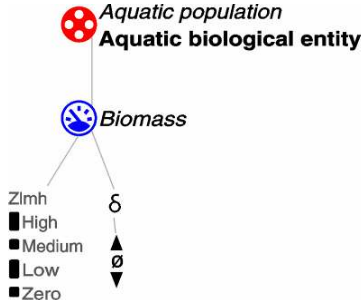
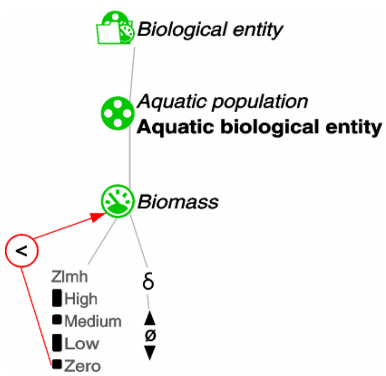


Figure 1.7.1 Biological entity - Static MF.

As in *Entity hierarchy*, *Aquatic population* subordinates both *Plant* and *Animal* aquatic species, this MF can be imported, as conditional MF, for constructing any other MF related to *Plant* or *Animal* species from the modelled system.

6. *Biological entity* MF has two children: *Population exists* (Figure 1.7.1.1), and *Population none existing* (Figure 1.7.1.2).



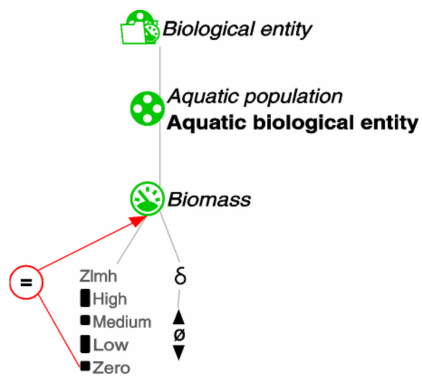


Figure 1.7.1.1 Population exists - Static MF. Figure 1.7.1.2 Population none existing - Static MF.

These MF are constructed to implement the two possible situation of any aquatic population *Biomass,* delimiting the population existence (Biomass > Zero) condition, from its extinction (Biomass = Zero) one.

7. The main system's water components involved in all aquatic processes are defined in Water reservoir MF (Figure 6.2 Water reservoir).

This MF shows all *Nutrient* forms as they result from physical, chemical and biologic processes, as follows:

- *Nutrient inflow*: Nutrient content in water that enters the system as result of Water flow physical process;
- *Nutrient consumption*: Nutrient content consumed (as biological process) by all aquatic *Plant* species, as their main food resource.
- *Nutrient available*: Nutrient content remained from *Nutrient inflow* after one part is consumed (*Nutrient consumption)* and one part is lost in the system (*Nutrient net loss*). This content assures the food resource for *Plants*.
- *Nutrient outflow*: Nutrient content that leaves the system.
- *Nutrient net loss* results as lost by *Nutrient consumption* and *Nutrient outflow*. As result of the Particulate Organic Matter bacterial decomposition biological process, inorganic components (e.g. *Nutrients*, *Heavy metals*, *Cyanotoxins*) are released (recycled) in water column, decreasing the *Nutrient net loss*.

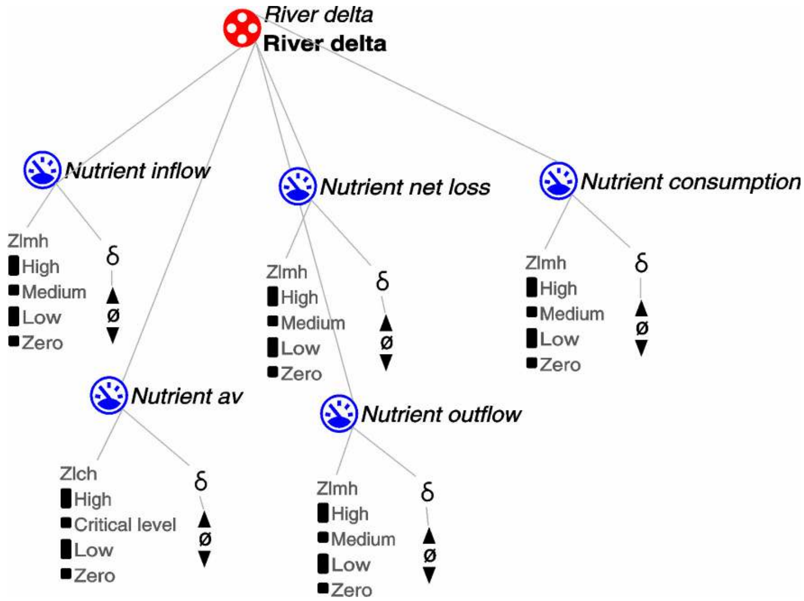
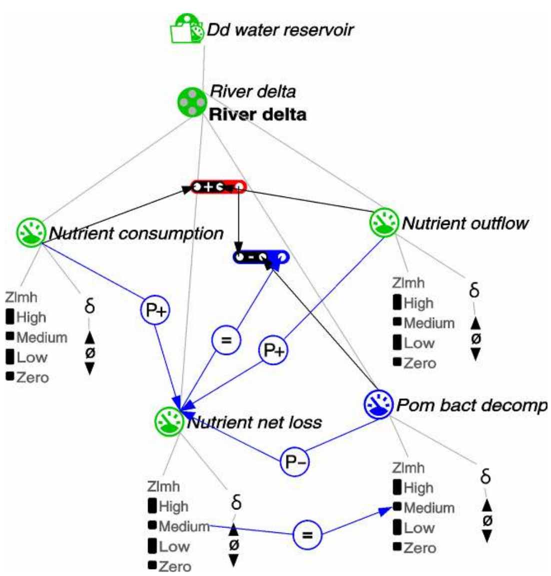


Figure 1.7.2 *Water reservoir* - Static MF.

The Water reservoir MF has two children: *Nutrient net loss* (Figure 1.7.2.1) and *Heavy metals net loss* (Figure 1.7.2.2).



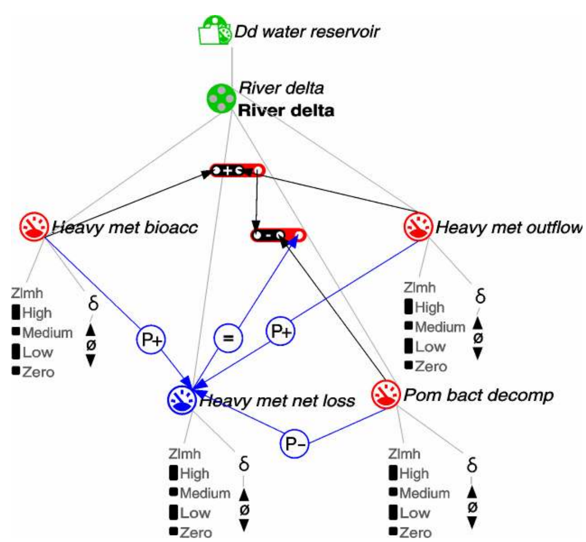


Figure 1.7.2.1 *Nutrient net loss* - Static MF. Figure 1.7.2.2 *Heavy metals net loss* - Static MF.

These MFs use "*Water reservoir"* MF as parent and add new Quantities, causal (Proportionalities, P+/P-) and mathematical dependencies (Equality, Plus/Minus) in order to define the relationship among Water quantities involved in constructing the two water quantities: *Nutrient net loss*, and *Heavy metals net loss*, respectively.

4. Aquatic population *Migration* (Figure 1.7.3) and *Mortality* (Figure 1.7.4) MFs: two MFs defining two features of any population.

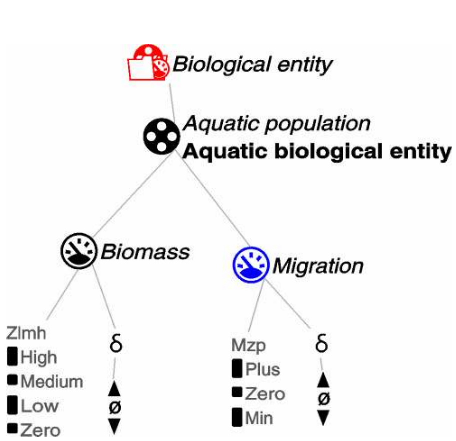


Figure 1.7.3 Migration- Static MF.

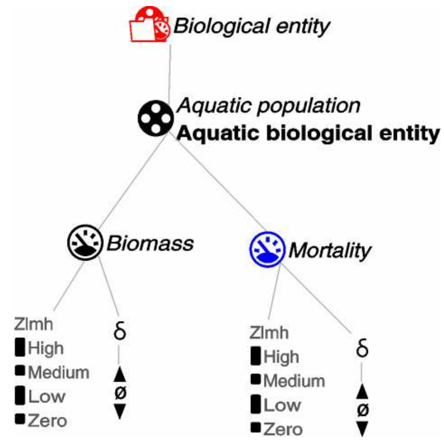
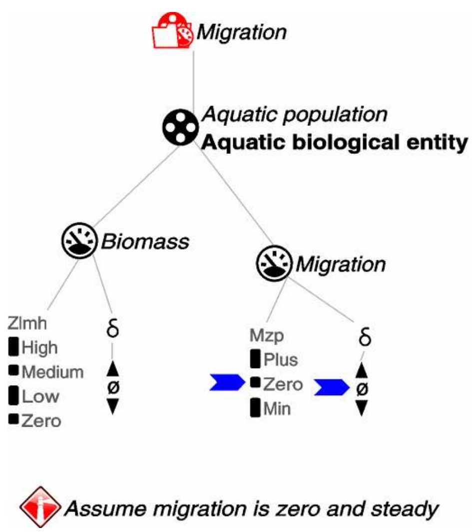


Figure 1.7.4 Mortality- Static MF.

These MFs use the imported, conditional MF "*Biological entity*" and add, as consequence the quantity *Migration*, and *Mortality*, respectively.

5. In order to provide certain perspectives on the simulation, or to reduce the simulation complexity, a number of five MFs have been constructed introducing certain *Assumptions*, as follows:

5.1. The two previous MFs, *Migration* and *Mortality*, are imported as conditional MF, to construct other MFs that introduce two Assumptions. These MFs are: *Assume migration is zero and steady* (Figure 1.7.5), and *Assume mortality is medium and steady* (Figure 1.7.6).



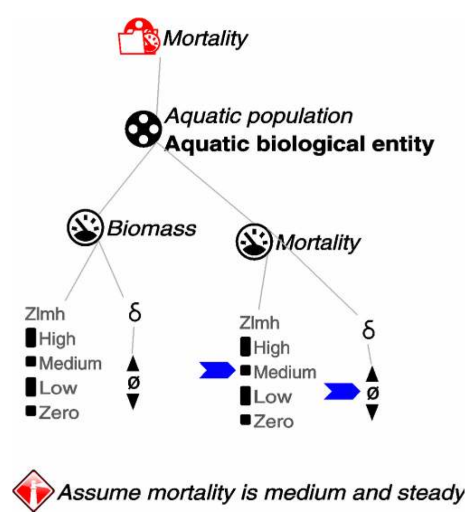


Figure 1.7.5 Assume migration is zero and steady- Static MF.

Figure 1.7.6 Assume mortality is medium and steady- Static MF.

To introduce the operating assumption that defines any aquatic population behaviour regarding its migration (immigration or emigration) and particularly a close population, there are assigned the value Zero and the Derivative Stable to *Migration*'s quantity, and the assumption "*Assume migration is zero and steady*" is added.

To introduce the simplifying assumption that defines any aquatic population behaviour regarding its mortality there are assigned the value Medium and the Derivative Stable to *Mortality*'s quantity, and the assumption "*Assume mortality is medium and steady*" is added.
Both population behavioural features, *Migration* and *Mortality*, contribute to population *Biomass* changes.

5.2 Assume medium equality for production and mortality (Figure 1.7.7)

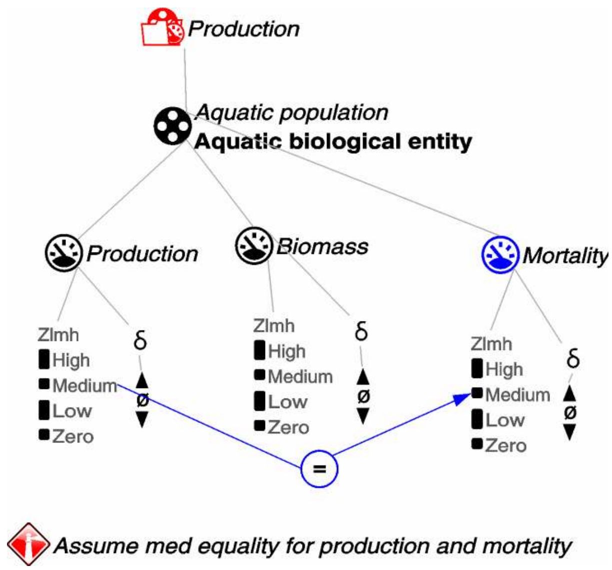


Figure 1.7.7 Assume equal medium production and mortality- Static MF.

This MF defines any *Aquatic population* relationship between its quantities *Production* and *Mortality*. It is constructed by importing the MF *Production* as condition and, as consequence, the Quantity *Mortality* is added. The Equality between Medium value of *Production* and *Mortality*, the assumption "*Assume medium equality for production and mortality*" is introduced.
This assumption introduces a constrain for the two quantities behaviour: to be equal when one of them are to medium value.

2.3 *Assume nutrient consumption Zero and steady* (Figure 1.7.8).

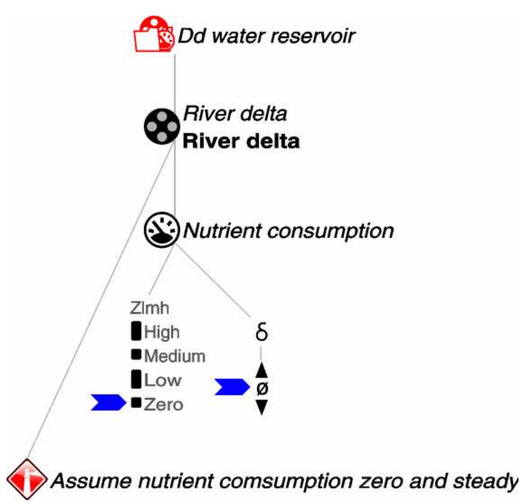


Figure 1.7.8 Assume nutrient consumption is Zero and steady - Static MF.

This MF is constructed by importing the MF DD water reservoir, as condition, assigning the value Zero and the Derivative Stable to *Nutrient consumption*'s quantity, and adding the assumption "*Assume nutrient consumption zero and steady*".

2.4 *Assume production is medium and steady* (Figure 1.7.9).

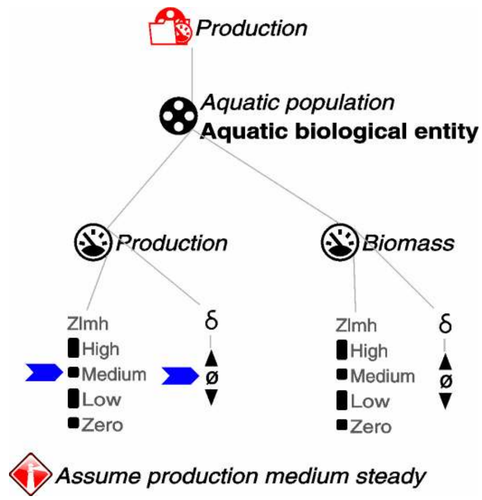
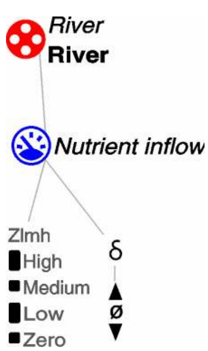
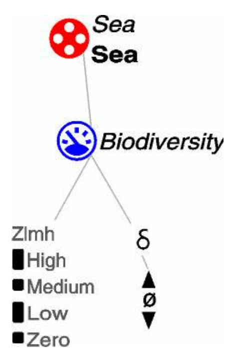


Figure 1.7.9 Assume production is medium and steady- Static MF.

This MF is constructed by importing the MF Production, as condition, assigning the value Medium and the Derivative Stable to Production's quantity, and adding the assumption "*Assume production is medium and steady*". This MF introduces a simplifying assumption to reduce the simulation complexity within the Functional Feeding Group relationship.

6. MFs defining the upstream (Figure 1.7.10 *Danube River*) downstream (Figure 1.7.11) *Western Black Sea*), and Danube Delta Human being system's components (Figure 1.7.12).





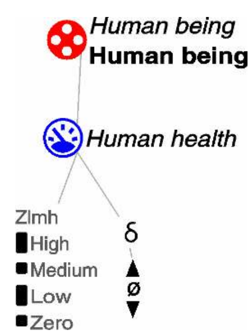


Figure 1.7.11 *Danube River* Figure 1.7.12 *Western Black Sea* Figure 1.7.13 *DD Human being*

1.7.2. Process Model Fragments

A Process Model fragments defines the system behavioural characteristics related to a process. For the Danube Delta Biosphere Reserve QR Model, a number of 39 Process Model fragments have been constructed and named as seen in Figure 1.7.14.

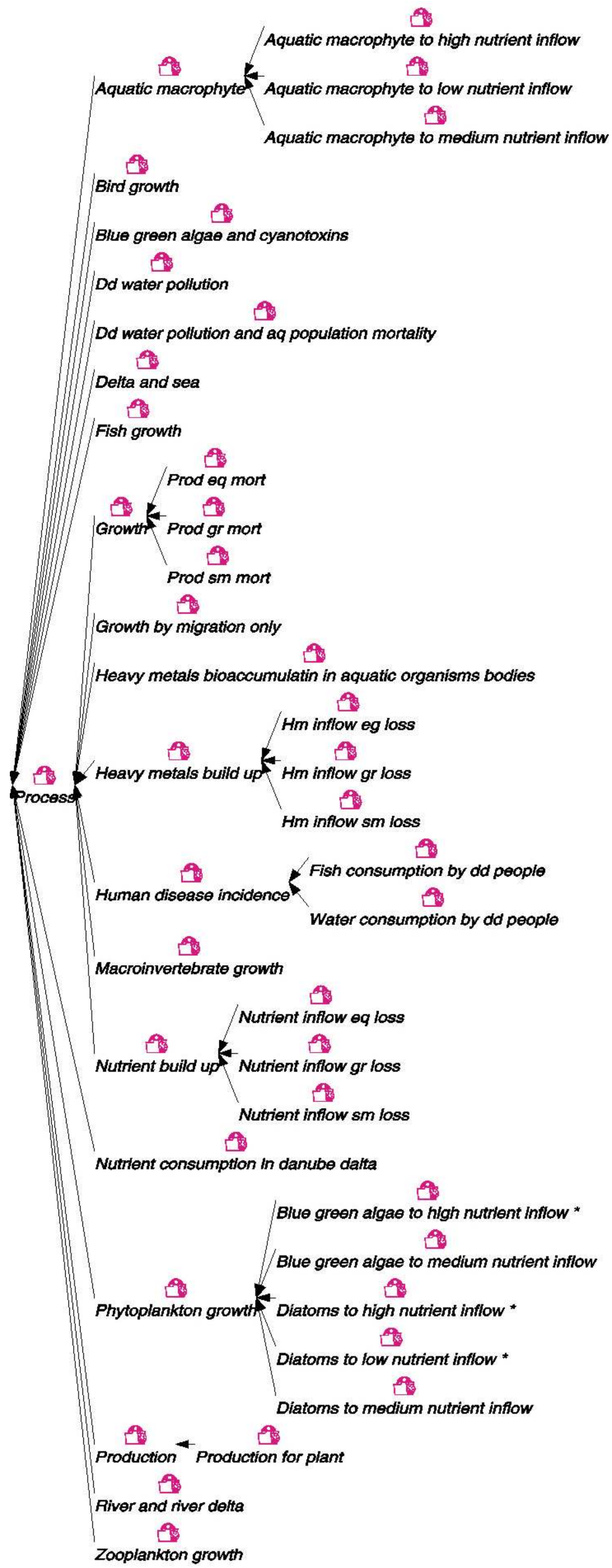


Figure 1.7.14 The DDBR QR Model Process Model Fragments name list.

1. The Model fragments defining the *Nutrients* behavioural features knowledge within the *Environment/Aquatic ecosystems* are: *Nutrient build up* and *River and river delta*.

1.1. *Nutrient build up* MF (Figure 1.7.15) figures the causal (P+, P-, I+), correspondence (Q) dependency relationship among the *River delta* Nutrients forms. It is constructed by importing the Static MF *DD water reservoir*, and adding the quantity *Nutrient build-up rate*. This *Nutrient* quantity in water (*Nutrient build-up rate*) results after one part from the Nutrient that enters the system (*Nutrient inflow*) is lost by different ways in the system (*Nutrient net loss*). The *Nutrient build-up rate* adds that Nutrient quantity in water (*Nutrient available*) which assures the aquatic *Plant* growth process. As *Nutrient build-up rate* results as difference (Minus) between *Nutrient inflow* and *Nutrient net loss*, it can take three values {Minus, Zero, Plus}, as *Nutrient inflow* can be smaller, equal, or higher than *Nutrient net loss.* For one of the three possibilities, *Nutrient inflow greater than Nutrient net loss* is figured in the MF shown in Figure 1.7.16.

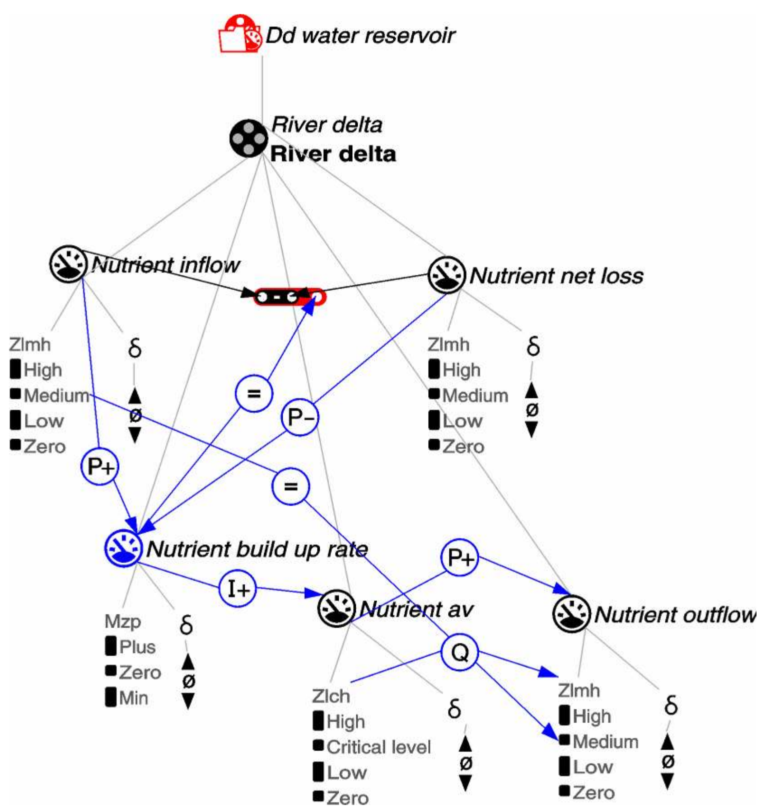


Figure 1.7.15 The *Nutrient build- up*- Process MF.

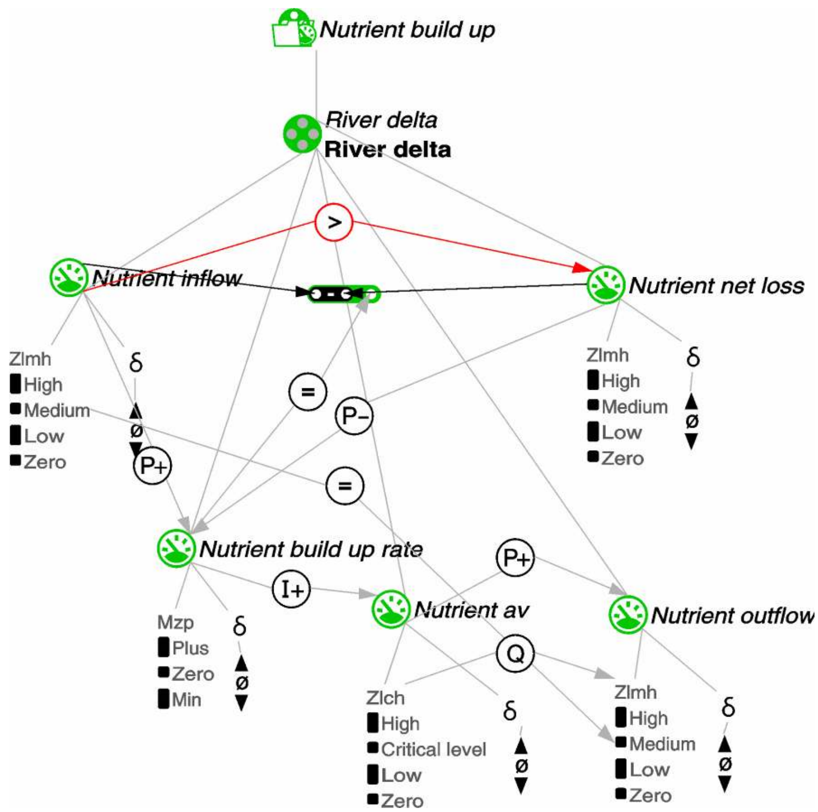


Figure 1.7.16 *Nutrient inflow greater than loss*- Process MF.

It is constructed as child of the *Nutrient build-up* parent MF, adding the inequality >, as condition, between *Nutrient inflow* and *Nutrient net loss*.

1.2. The *River and river delta* MF (Figure 1.7.17) figures the structural ("*Flows into*"), causal

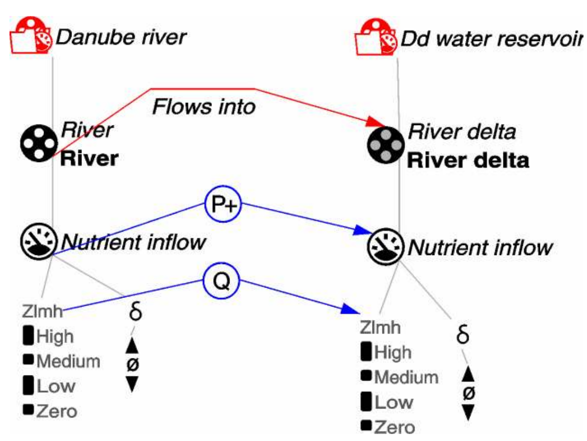


Figure 1.7.17 *River and river delta* - Process MF.

(P+), and correspondence (Q) dependency relationships between the two *Aquatic ecosystems*: *River* and *River Delta* related to the *Nutrient* resource for the *River Delta*.

2. The Model fragments defining the aquatic *Plant* behavioural features knowledge regarding its growth process are:
2.1 *Growth*
2.2 *Growth by Migration only*
2.3 *Nutrient consumption* by *Plant*
2.4 *Production*
2.5 *Production for Plant*
2.6 *Aquatic macrophyte*
2.7 *Phytoplankton growth*

To construct the *Growth* MF, (Figure 1.7.18 The Aquatic Plant *Growth* Process MF), three MFs are imported, as conditional MFs (*Production*, *Population exists*, and *Mortality*), and the *Growth* quantity is added. In any *Plant* growth process, *Production* contributes proportionally positive (P+) to the *Plant* growth, instead *Mortality* contributes with P-.

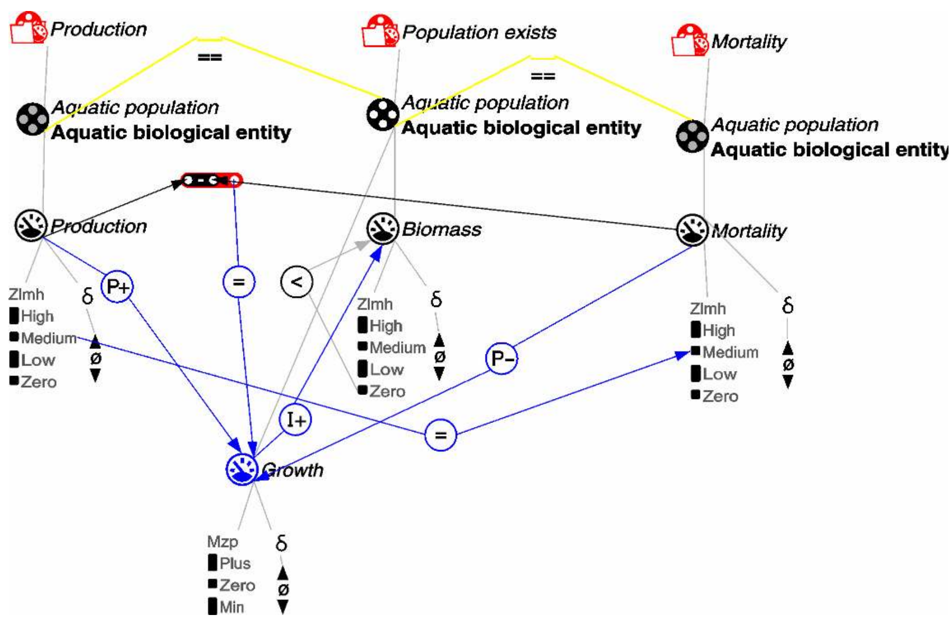


Figure 1.7.18 Aquatic Plant *Growth*- Process MF.

Thus, for the *Plant*: *Growth rate* the mathematical calculus (Minus, meaning difference between *Production* and *Mortality*) can be used. The *Plant*: *Biomass* quantity is positive direct influenced (I+) by *Growth*. Equality between *Production* and *Mortality* to their Medium values is introduced, in order to reduce the simulation complexity.
The *Growth* MF has three children for the three possible conditions regarding the *Plant*: *Production* and *Mortality* quantities:

- *Production* greater than *Mortality*;
- *Production* equals *Mortality*
- *Production* smaller than *Mortality*.

In this paper, as example of these MFs, the one that defines the condition *Production greater than Mortality* is shown in Figure 1.7.19.

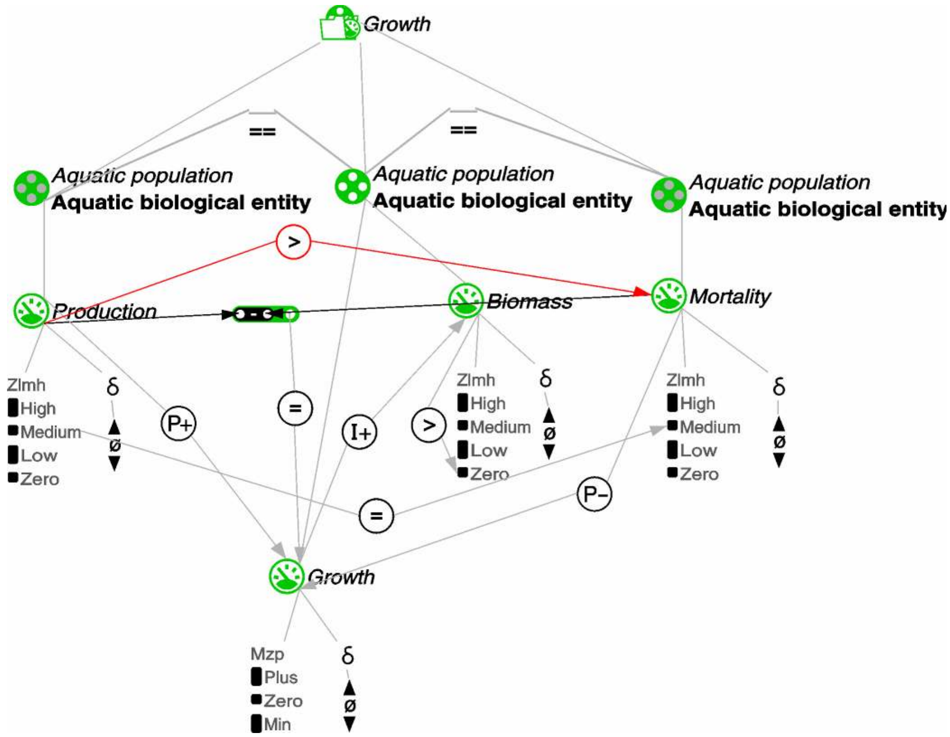


Figure 1.7.19 Production greater than Mortality- Process MF.

This MF is constructed by adding to the parent MF *Growth* the Inequality mathematical dependency, Greater than (>), between *Production* and *Mortality*, as condition.

2.2. *Growth by Migration only* MF (Figure 1.7.20).

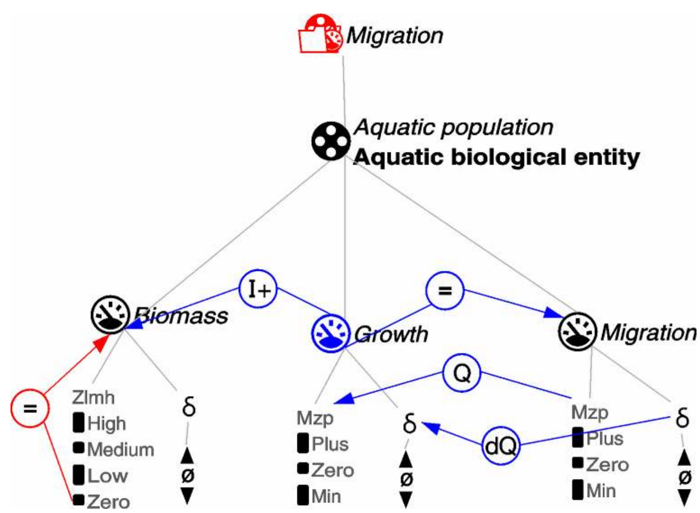


Figure 1.7.20 The *Plant Growth by Migration only*- Process MF.

This MF defines the possible situation when population *Growth* is based on *Migration* only. As there exists one more MF related to *Migration feature*, "*Assume migration is zero and steady*" (Figure 6.3.1), regardless of the *Production* and *Mortality* values, these two MFs will define the process condition when *Plant*: *Growth* is Zero, meaning the *Biomass* is Zero too. This condition figures that the *Plant*: *Growth* process stops.

2.3 *Nutrient consumption* by *Plant* MF (Figure 1.7.21) shows a strong dependency relationship between any aquatic *Plant*: *Biomass* and the environment it belongs, by causal (P+) and correspondence (Q, dQ) dependency.

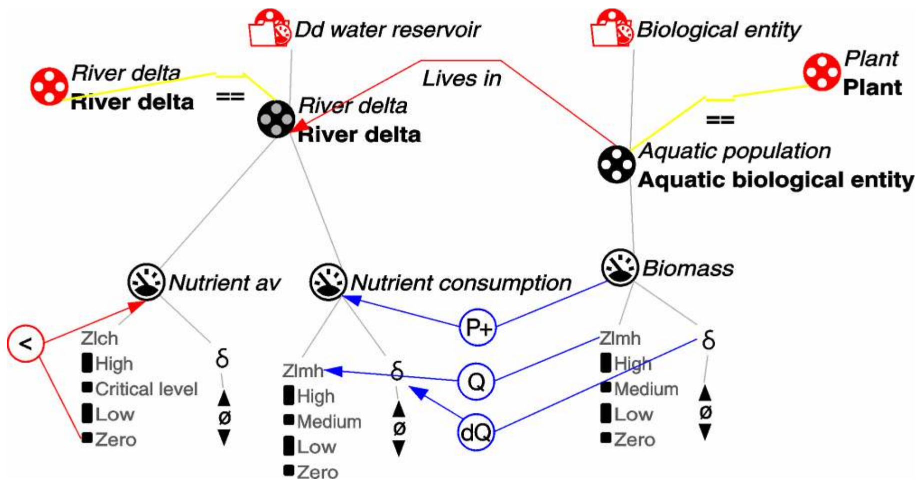


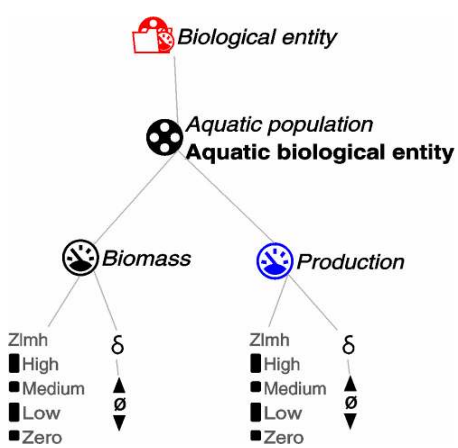
Figure 1.7.21 Nutrient consumption by Plant- Process MF.

In order to be possible a *River Delta*: *Nutrient consumption* – *Aquatic population* (*Plant*): *Biomass* relationship, *River Delta*: *Nutrient available* quantity > Zero as condition is introduced. It shows that the *Plant*: *Biomass* to be higher than Zero needs indirectly that *Nutrient available* to be>Zero.

2.4. *Production* MF (Figure 1.7.22) is constructed by importing the *Biological entity* MF, as condition MF, and adding the quantity *Production*.

2.5. *Production for Plant* MF (Figure 1.7.23) is constructed by importing the *Dd water reservoir* MF, as condition, to the *Production* parent MF, and the *Plant* entity (identical == with *Aquatic population* entity). This MF construction shows:

- the configuration, "*Lives in*", as condition, between the *Aquatic population* and the environment, *River delta*;
- causal (P+) and correspondence (Q, dQ) dependency relationship between aquatic *Plant* and Environment, *River Delta*: *Nutrient available*.



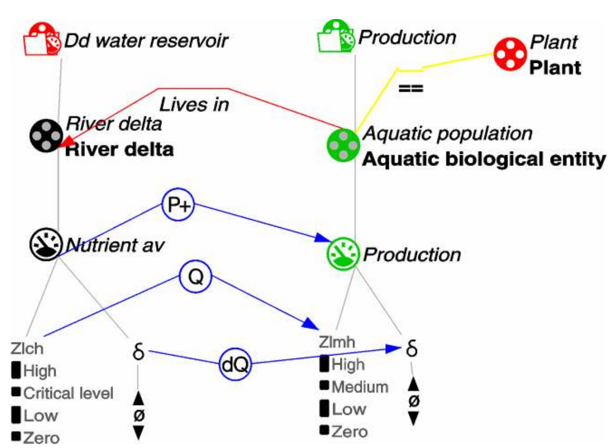


Figure 1.7.22 *Production*- Process MF. Figure 1.7.23 *Production for Plant*- Process MF

2.6 MFs related to Aquatic macrophyte are not presented in this paper as they have the same structure as *Phytoplankton growth* MFs, described below.

2.7. *Phytoplankton growth* MF (Figure 1.7.24) structures one of the aquatic *Plants* (*Phytoplankton*) and Environment behavioural components information in the framework of the *Plant* growth process. It is constructed by importing the conditional MF "*Production for Plant*" and adding the *Phytoplankton* entity, as condition (identical "**==**" with *Plant* entity), and the *River Delta*: *Temperature* quantity, also as condition. The positive proportionality (P+) relationship which exists between *River Delta*: *Temperature* and *Plant*: *Production* is added.

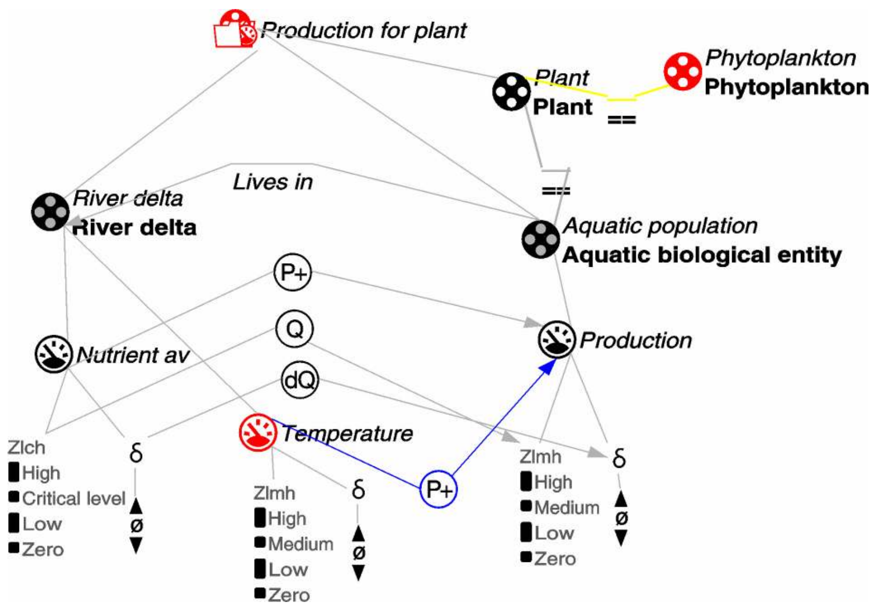


Figure 1.7.24 *Phytoplankton growth* - Process MF.

Phytoplankton group *Plant* contains two main different populations, *Diatoms* (algae species) and *Blue-green algae* (bacteria species). They have different roles within the *Aquatic population* Functional Feeding Group relationship (See Table 1.1 Danube Delta Biosphere Reserve system: Entity summary). Also they behave differently to the same Environment conditions, such as: *River Delta*: *Nutrient available*, and *Temperature.* That's why, to model the two species behaviour, 5 MFs have been constructed, as children of *Phytoplankton growth* MF, as follows:

2.7.1 *Diatoms to low nutrient inflow*. This MF exemplifies all *Plant* species (*Phytoplankton* and *Aquatic Macrophytes*) behavioural features knowledge, as all of them have the same behaviour to the Environment condition: *River Delta*: *Nutrient inflow* low.

2.7.2 *Diatoms to medium nutrient inflow*;

2.7.3 *Diatoms to high nutrient inflow*;

2.7.4 *Blue-green algae to medium nutrient inflow*;

2.7.5 *Blue-green algae to high nutrient inflow*;

2.7.6 *Blue-green algae and Cyanotoxins production*.

As *Aquatic Macrophytes* have the same behaviour as *Blue-green algae* species, there are not constructed MFs for this *Plant* species.

In this paper, from the above listed MFs (2.7.1 ÷ 2.7.5) two MFs are described and these are:

2.7.3 *Diatoms to high Nutrient inflow* MF (Figure 1.7.25). This MF is constructed by adding to the *Phytoplankton growth* MF parent the entity *Diatoms*, as condition (identical "==" with *Phytoplankton*). The value High of *River Delta*: *Nutrient inflow* is assigned, as condition (in red), meaning that there is modelled the system behaviour restricted (reduced) to this particular condition. The *Temperature* takes all possible values: ≥ Zero, also as condition. As consequence (in blue colour), the *Diatoms*: *Production* takes all values, strictly > Zero because it is indirectly positively (P+, Q, dQ) influenced by *River Delta*: *Nutrient available* which in natural aquatic ecosystem always is > Zero.

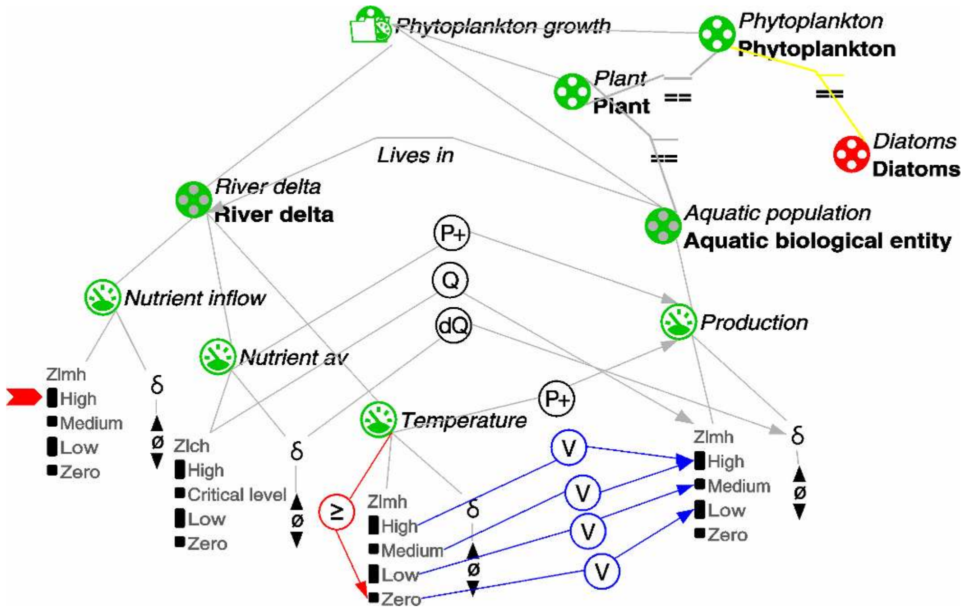


Figure 1.7.25 *Diatoms growth to high Nutrient inflow* - Process MF.

When *River Delta*: *Nutrient inflow* has the High concentration in water, *Diatoms*: *Production* reaches the value High both for Medium and High *River Delta*: *Temperature*. That means there takes place the so-called "Diatoms bloom" which indicates the water eutrophication condition (high level of Nutrients concentration in water), and a very low water quality for *Aquatic populations* life condition.

2.7.5 *Blue-green algae to high Nutrient inflow* (Figure 1.7.26). This MF is constructed as the above MF (Figure 1.7.25) by adding the entity *Blue-green algae*, as condition, (identical == with *Phytoplankton* entity).

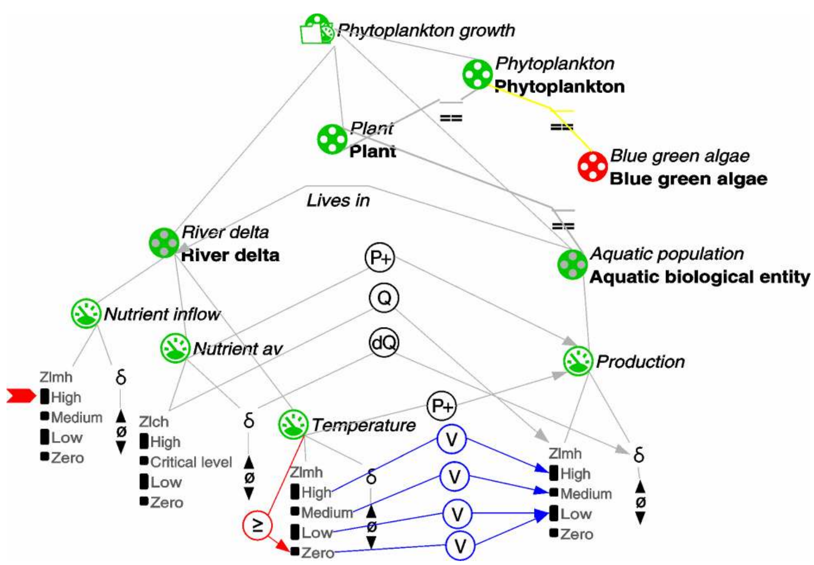


Figure 1.7.26 *Blue-green algae growth process to high Nutrient inflow* - Process MF.

When *River Delta*: *Nutrient inflow* has the High concentration in water, *Blue-green algae*: *Production* reaches the value High only High *River Delta*: *Temperature*. That means that “Blue-green algae bloom” takes place in the same time with “Diatoms bloom” only for the condition: both *Nutrient inflow* and *Temperature* are to their maximum value: High. When both Diatoms bloom and Blue-green algae bloom occur in the same time, it indicates a High degree of water pollution, and a high lack of oxygen in water, meaning very poor, or almost no life conditions for *Aquatic populations*.

2.8 *Blue-green algae and Cyanotoxins* MF (Figure 1.7.27).

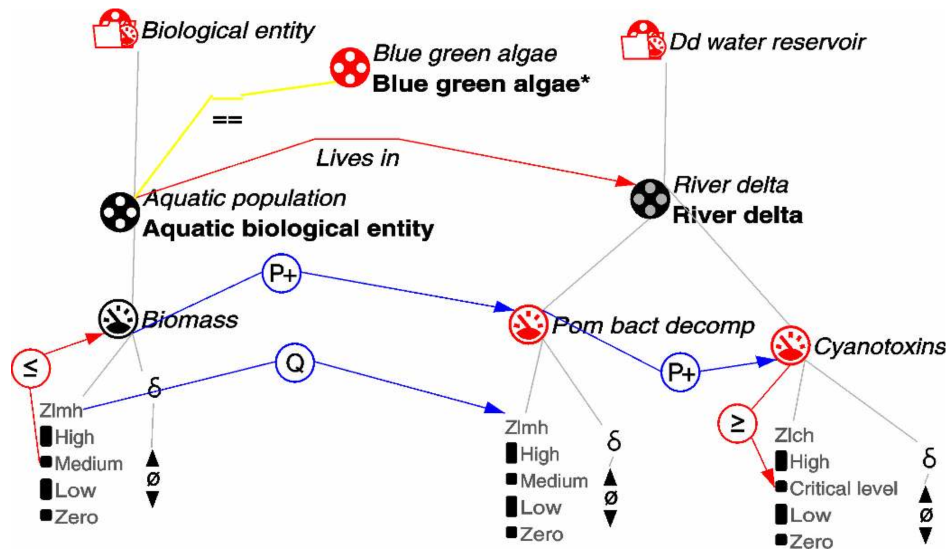


Figure 1.7.27 *Blue-green algae and Cyanotoxins* - Process MF.

This MF figures the production of *River delta*: *Cyanotoxins* (one of the main water pollutants), as result of the biological process of Particulate Organic Matter bacterial decomposition (named shortly *Pom bact decomp*) of aquatic plant *Blue-green algae*.

3 Model fragments defining the aquatic *Animal* behavioural features knowledge regarding its growth process are:
3.1 *Zooplankton growth process* (Figure 1.7.28);
3.2 *Fish growth process* (Figure 1.7.29);
3.3 *Bird growth process* (Figure 1.7.30);
3.4 *Macroinvertebrate growth process* (Figure 1.7.31).

These MFs figure the structural and behavioural correlations between two Aquatic populations, which in the framework of the Functional Feeding Group relationships have different roles: one is the predator and the other one is the prey.

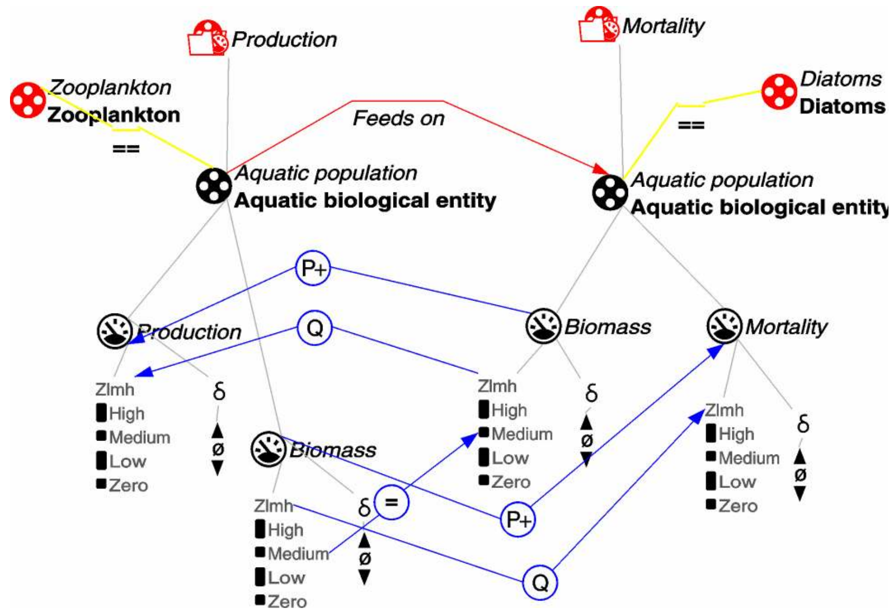


Figure 1.7.28 *Zooplankton growth process* - Process MF.

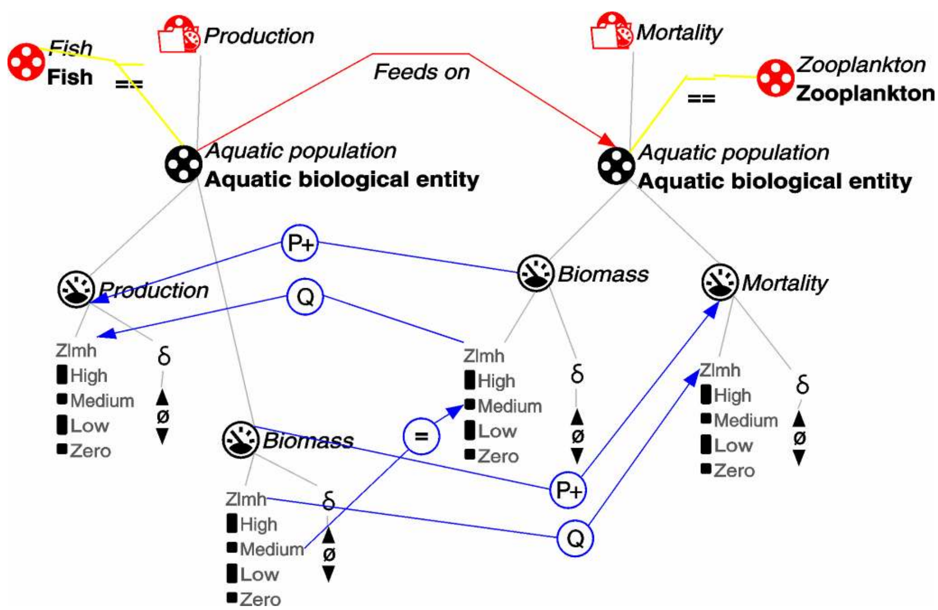


Figure 1.7.29 *Fish growth process* - Process MF.

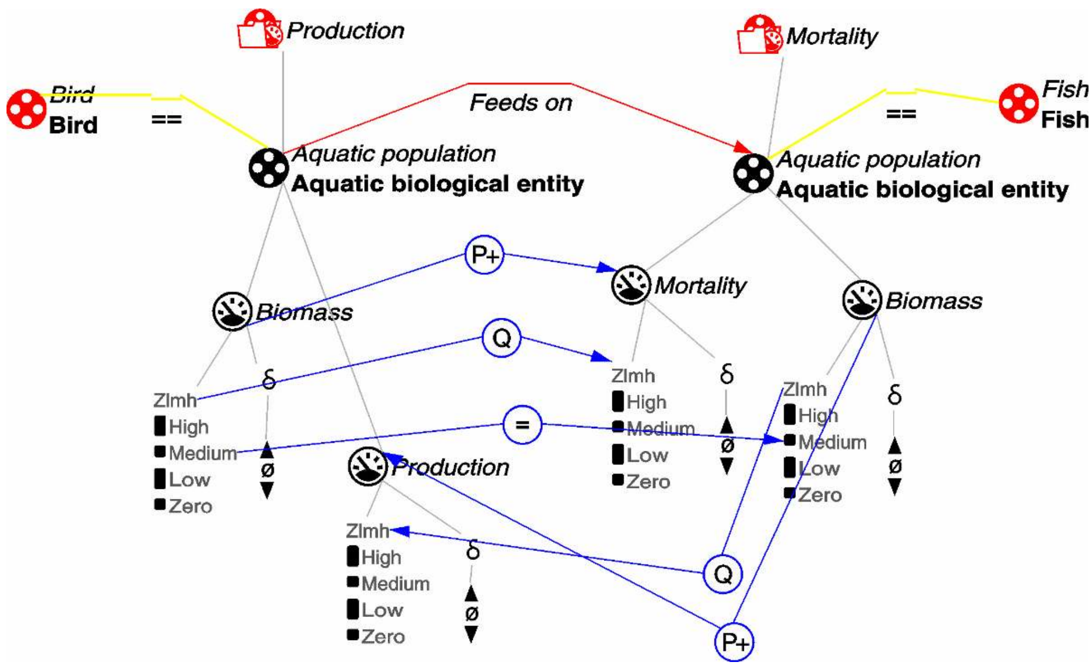


Figure 1.7.30 *Bird growth process* - Process MF.

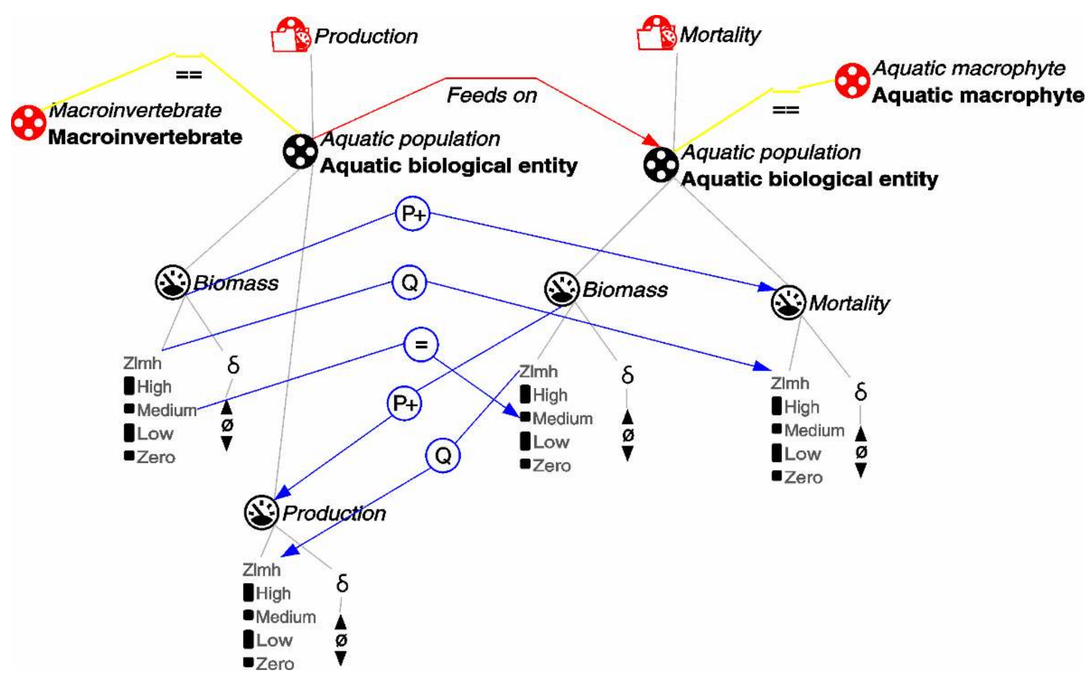


Figure 1.7.31 *Macroinvertebrate growth process* - Process MF.

The same principle is used in constructing all of these MFs (1.7.28 ÷ 1.7.31), as follows:

- there are imported, as conditional MFs, both the *Production* MF addressing the predator *Aquatic population* species., and *Mortality* MF addressing the prey *Aquatic population* species;

- the configuration "*Feeds on*" is added as condition;
- the causal (P+) and correspondence (Q) dependency relationships between predator *Aquatic population*: *Biomass* and prey *Aquatic population*: *Mortality* are implemented;
- the causal (P+) and correspondence (Q) dependency relationships between prey *Aquatic population*: *Biomass* and prey *Aquatic population*: *Production* are implemented.

4 The Model fragments defining the system *Heavy metals* behavioural features knowledge regarding this water pollutant forms, are:

4.1 *Heavy metals build-up* (Figure 1.7.32);

4.2 *Heavy metals inflow greater than heavy metals net loss* (Figure 1.7.33);

4.3 *Heavy metals bioaccumulation in aquatic organism bodies* (Figure 1.7.34).

The MF *Heavy metals build-up* (Figure 1.7.32) figures the causal (P+, P-, I+), correspondence (Q) dependency relationship among the *River delta*: *Heavy metals* forms.
It is constructed by importing the Static MFs *Danube River* and *DD water reservoir*. The configuration "*Flows into*" is added as condition.
All model quantities are added as consequence, excepting *Heavy metals net loss* which is added as condition. This *Heavy metals* quantity in water (*Heavy metals build-up rate*) results after one part from the *Heavy metals* that enters the system (*Heavy metals inflow*) is lost by different ways in the system (*Heavy metals net loss*).

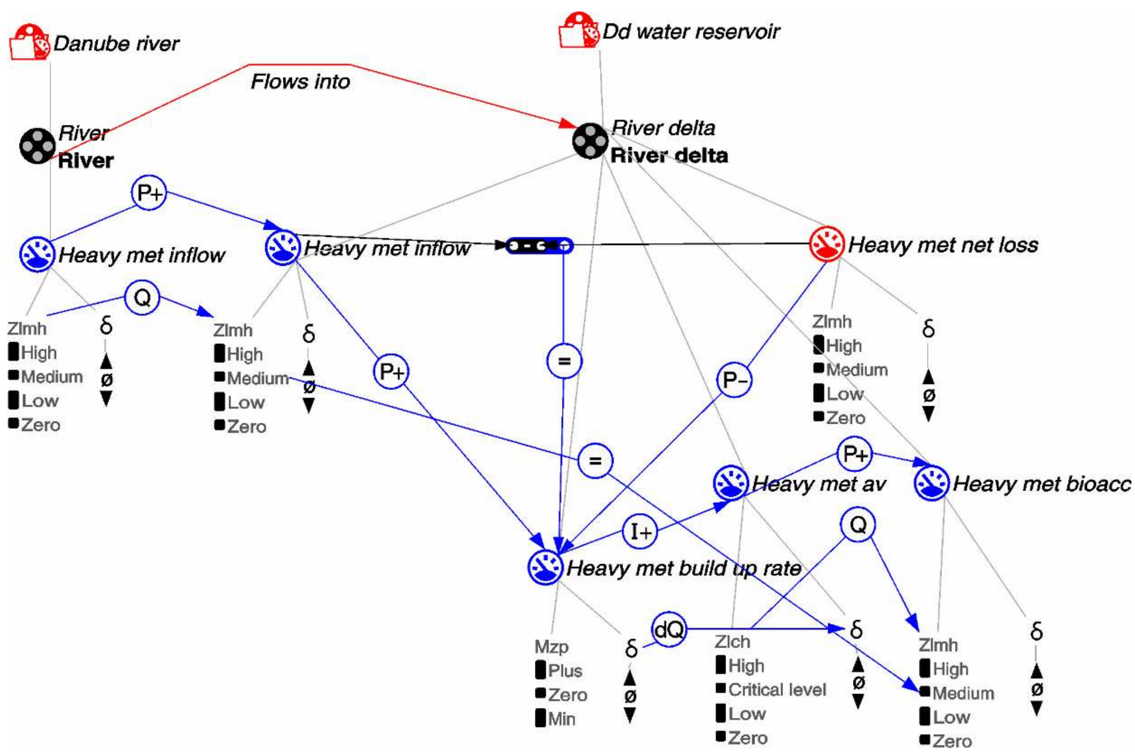


Figure 1.7.32 *Heavy metals build-up* - Process MF.

The *Heavy metals build-up rate* quantity adds *Heavy metals* quantity in water (*Heavy metals available*) which "contributes" to the *Water pollution process* (See Figure 1.7.35 *Water pollution process* MF). As *Heavy metals build-up rate* results as difference between *Heavy metals inflow* and *Heavy metals net loss*, it can take three possible values {Minus, Zero, Plus}, as *Heavy metals inflow* can be smaller, equal, or higher than *Heavy metals net loss*. As example for the three possible system conditions, the *Heavy metals inflow* greater than *Nutrient net loss* one is figured in the MF shown in Figure 1.7.33.

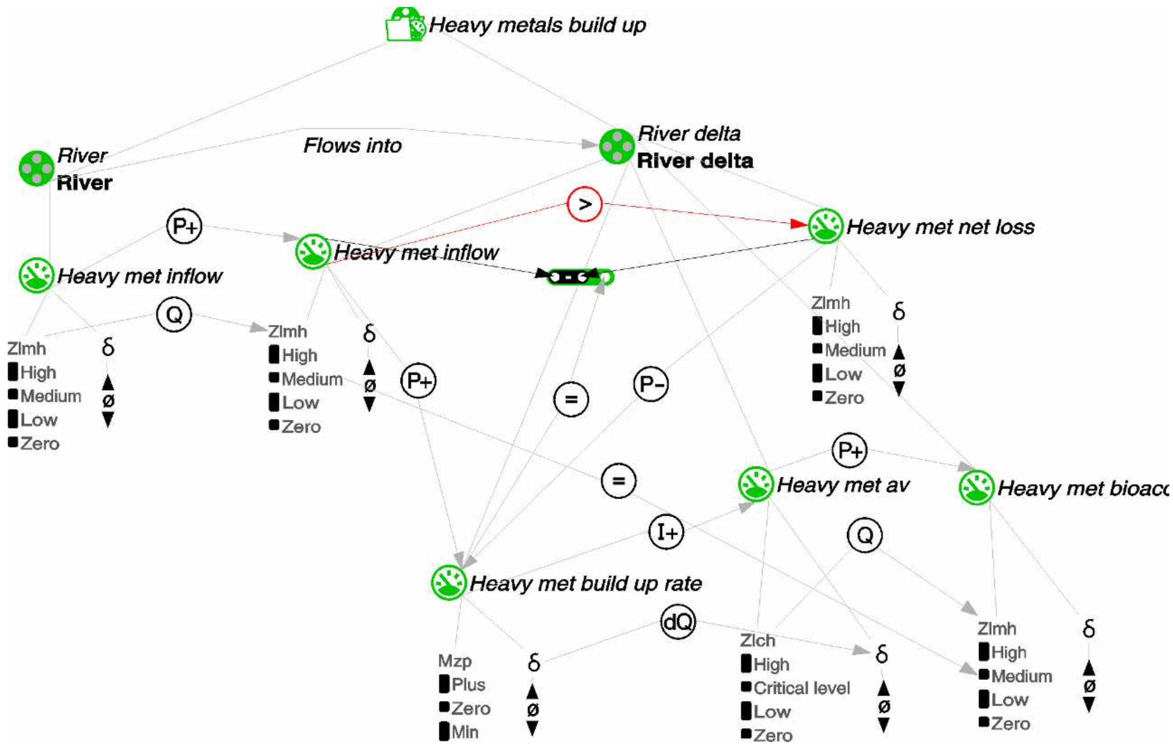


Figure 1.7.33 *Heavy metals inflow greater than heavy metals net loss* - Process MF.

The *Heavy metals inflow greater than heavy metals net loss* MF (Figure 1.7.33) is constructed as one of the three children of *Heavy metals build-up* parent MF (Figure 1.7.32) to which the inequality, ">" is added as condition (in red colour), between the two compared *Heavy metals* forms: *Heavy metals inflow* and *Heavy metals net loss*.

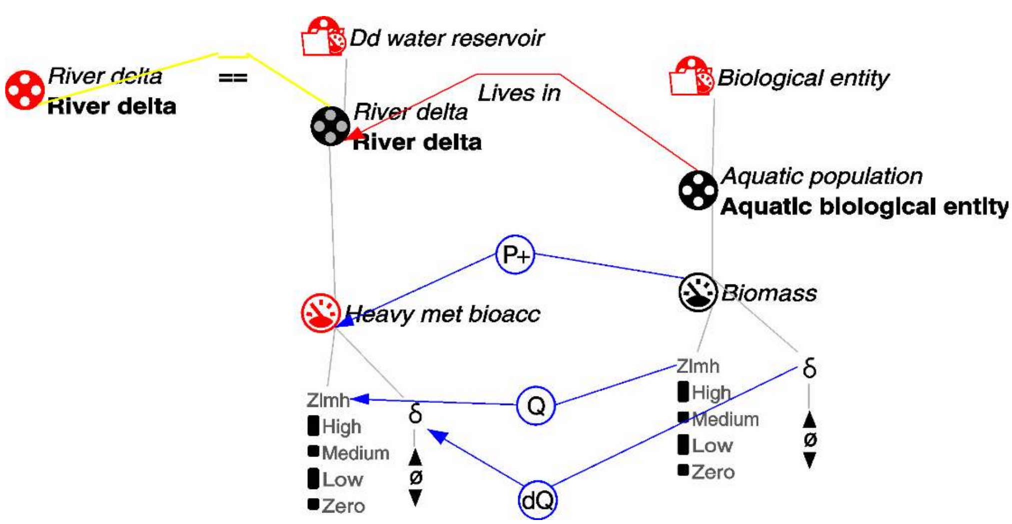


Figure 1.7.34 *Heavy metals bioaccumulation in aquatic organism bodies* - Process MF.

The *Heavy metals bioaccumulation in aquatic organism bodies* MF (Figure 1.7.34) figures the structural and behavioural relationships between any *Aquatic population* and the *River delta*, regarding the *Aquatic population*: *Biomass* and one of the *River delta*: *Heavy metals* forms in

water, *Heavy metals bioaccumulation in aquatic organism bodies* (shortly named as *Heavy met bioacc*).
This MF is constructed by importing both the *DD water reservoir* and *Biological entity*, as conditional MFs.
The *Heavy metals bioaccumulation in aquatic organism bodies* has the same role as *Nutrient consumption* by any aquatic Plant species, this *Heavy metals* form is "consumed" by any aquatic organism body, by bioaccumulation. Thus, this *Heavy metals* form constitutes one of the *Heavy metals net loss* quantities (along with *Heavy metals outflow*, as shown in Figure 1.7.2.2 *Heavy metals net loss* Static MF).
Between any *Aquatic population*: *Biomass* and the *River delta*: *Heavy metals bioaccumulation in aquatic organism bodies* a close correlation exists within their behaviour, figured qualitatively by positive proportionality (P+) and direct correspondence (Q, dQ).

5 Model fragments defining the *Water pollution* behavioural features knowledge regarding this water chemical process are:
   5.1. *DD Water pollution process* (Figure 1.7.35);
   5.2. *DD Water pollution and dd aquatic population biodiversity* (Figure 1.7.36);
   5.3. *DD Water pollution and Black Sea biodiversity* (Figure 1.7.37).

The *DD Water pollution process* MF (Figure 1.7.35) figures the main water pollutants behaviour related to the *Water pollution* process. The *Water pollution* rate is positively indirectly influenced (P+) by all water pollutants: *Nutrient available*, *Heavy metals available*, and *Cyanotoxins*.

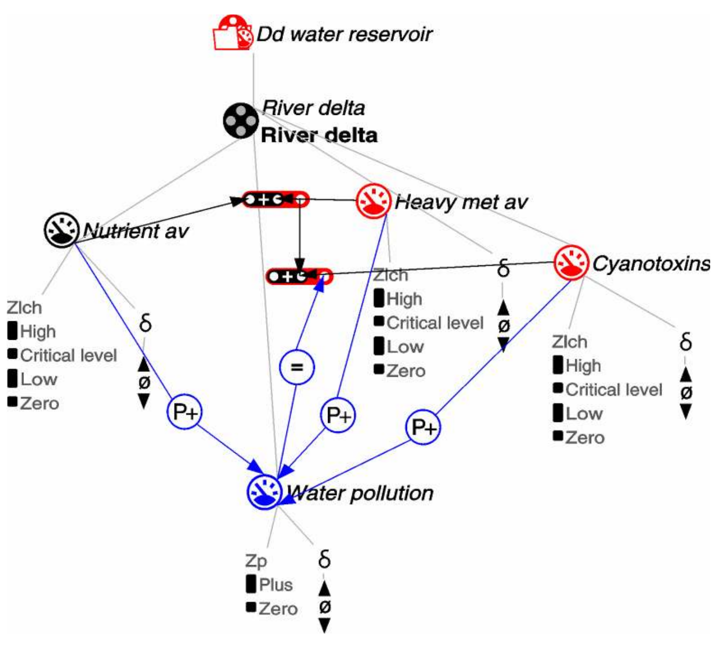


Figure 1.7.35 *DD Water pollution process*- Process MF.

This MF is constructed by importing the MF *DD water reservoir*, as condition, adding *Heavy metals available*, and *Cyanotoxins* quantities, as condition, and *Water pollution* rate quantity, as consequence.

The *DD Water pollution and dd aquatic population biodiversity* MF (Figure 1.7.36) figures the structural and behavioural relationships between *River delta* and the *Aquatic population*, related to *River delta*: *Water pollution* influence on *Aquatic population* components behaviour.

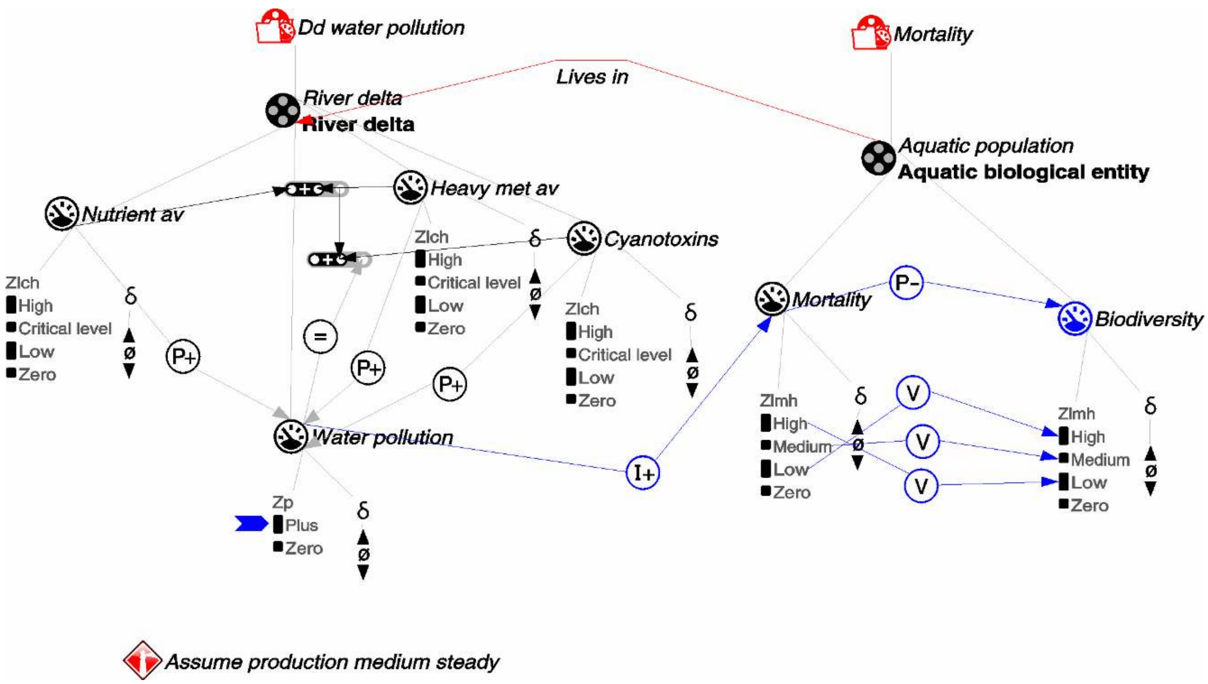


Figure 1.7.36 *DD Water pollution and dd aquatic population biodiversity* - Process MF.

The MF is constructed by importing both *DD water pollution* and *Mortality*, as conditional MFs. The configuration "*Lives in*" introduces the structural relationship indicating that *Aquatic population* entity is part of the *River delta* entity.
Aquatic population: *Biodiversity* is added as consequence.
For the *Water pollution* process to take effect, the value Plus of this quantity is assigned.
As consequence, the *River delta*: *Water pollution* rate has a direct positive influence on *Aquatic population*: *Mortality*. Therefore a causal dependency (I+) is figured between them. A negative proportionality (P-) causal dependency relationship exists between *Aquatic population*: *Mortality* and *Biodiversity*.
To reduce the simulation complexity, the correspondence (V) dependency between the *Aquatic population*: *Mortality* and *Biodiversity* values, and the assumption "*Assume production medium steady*" are added.

The *DD Water pollution and Black Sea biodiversity* MF (Figure 1.7.37) figures the structural and behavioural relationships between *River delta* and the *Western Black Sea*: *Biodiversity* behaviour, related to *River delta*: *Water pollution* influence on *Western Black Sea*: *Biodiversity* component behaviour.
The MF is constructed by importing both *DD water pollution* and *Western Black Sea*, as conditional MFs. The configuration "*Flows into*" introduces the structural relationship between these two entities.
For the *Water pollution* process to take effect, the value Plus of this quantity is assigned, as condition, and as consequence the *River delta*: *Water pollution* rate has a direct negative influence (I-) on *Western Black Sea*: *Biodiversity*.

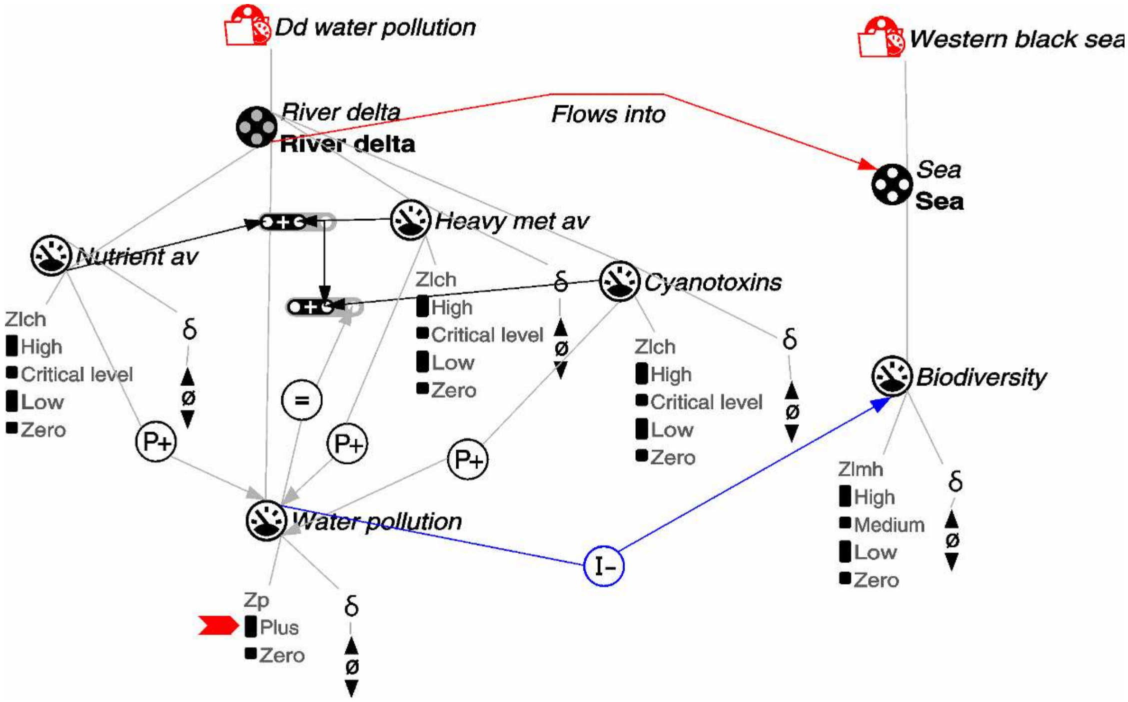


Figure 1.7.37 *DD Water pollution and Black Sea biodiversity* - Process MF.

6 Model fragments defining the *Human being* behavioural features knowledge regarding the *Human health* aspects, for those people living in or around the modelled system, related to the system's Water and Fish quality. The MFs are:
 6.1 *Human being health* (Figure 1.7.38);
 6.2 *Human being health affected by water consumption* (Figure 1.7.39);
 6.3 *Human being health affected by fish consumption* (Figure 1.7.40).

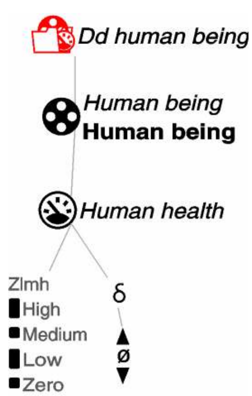


Figure 1.7.38 *Human being health* MF.

The *Human being health* MF shows the only modelled *Human being* quantity: *Human health*. The MF is imported, as conditional MF, and constitutes the parent MF for the two children deriving from this.

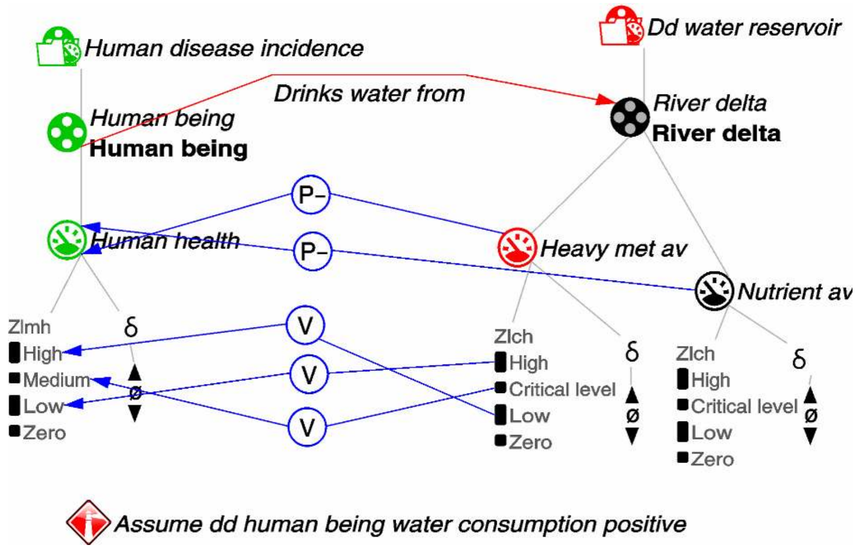


Figure 1.7.39 *Human being health influenced by water consumption* - Process MF.

The *Human being health affected by water consumption* MF models the existent correlation between the two main water pollutants (*Nutrients* and *Heavy metals*) and the *Human health*, if the assumption "*Assume dd water human being water consumption positive*" is true.
Both *Nutrients* and especially the *Heavy metals* have a negative indirect influence, negative Proportionality, on *Human being health*.
To reduce the simulation complexity, correspondence (V) dependency relationships between the *River delta*: *Heavy metals available* and *Human health* values have been figured.
Nutrient available has a negative effect on *Human health* only if in High value.

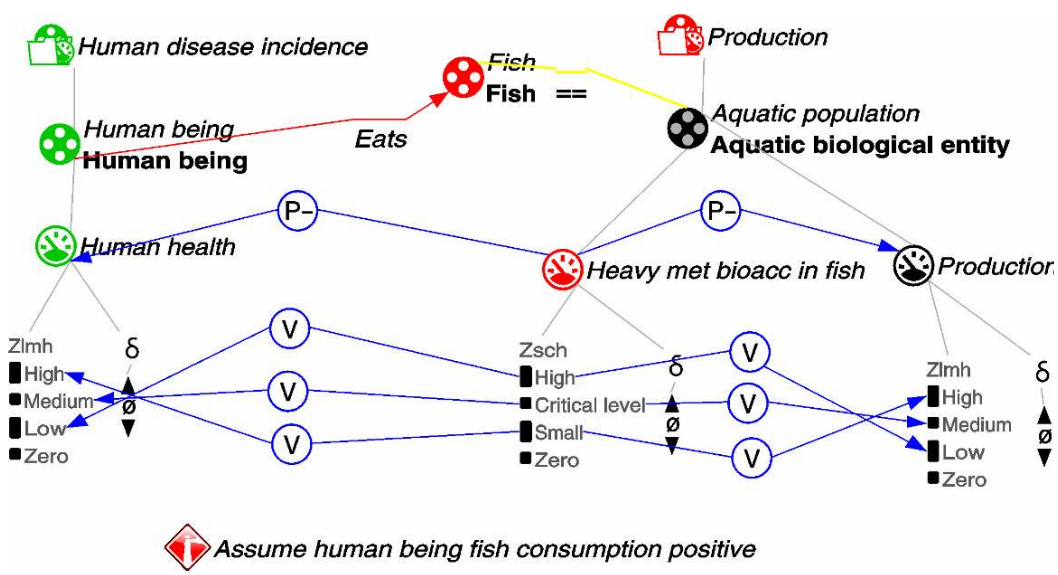


Figure 1.7.40 *Human being health influenced by fish consumption* - Process MF.

The *Human being health affected by Fish consumption* MF models the existent correlation between the *Fish*: *Heavy metals bioaccumulated in fish (muscle tissue)* and the *Human health*, if the assumption "*Assume human being fish consumption positive*" is true.

Heavy metals bioaccumulated in fish (muscle tissue) has a negative indirect influence, negative Proportionality (P-), on *Human being health*. To reduce the simulation complexity, correspondence (V) dependency relationships between the Fish: *Heavy metals bioaccumulated in fish* and *Human health / Fish*: *Production* values have been figured.

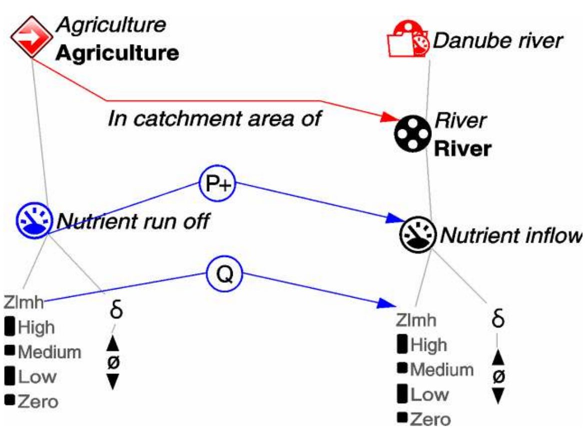
1.7.3. Agent Model Fragments

The *Agent Model fragment*s define the Agents behavioural features knowledge regarding their effects on the modelled system components.
These MFs are introduced in the DDBR QR Model to figure the most important water pollutants (*Nutrients* and *Heavy metals*) as external influence on the modelled system components behaviour.
There are two *Agent* MFs constructed for the two Agents of the modelled system (Figure 1.7.41. The Agent Model fragments name list).

Figure 1.7.41 The Agent Model fragments name list.

These are:

1. *Nutrient run-off by Agriculture* (Figure 1.7.42);
2. *Heavy metals run-off from Industry* (Figure 1.7.43).



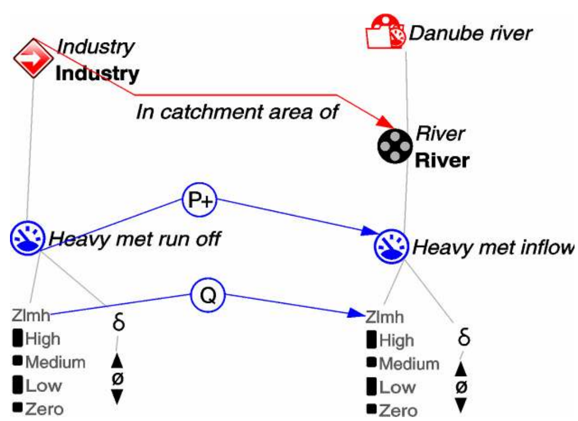


Figure 1.7.42 *Nutrient run-off by Agriculture* Figure 1.7.43 *Heavy metals run-off from industry*

The MFs are constructed by introducing the two Agents with their specific quantity *Agriculture*: *Nutrient run-off* and *Industry*: *Heavy metals run-off*, respectively. The configuration "*In catchment area of*" shows that the two main water pollutants run-off takes place at the entire hydrographic basin scale of the *River*. The MF *Danube River* is imported, as conditional MF. As there is a strong correlation between the two quantities of the *Agent* and *River* entity, respectively, *Nutrient run-off* / *Heavy metals run-off* and *Nutrient inflow* / *Heavy metals inflow* a positive proportionality (P+) and a correspondence (Q) are introduced used.

2. Simulation results

Scenarios concerning the aquatic *Plant* growth process

State graph

2.1. Scenarios

The Scenarios constructed to model the DDBR aquatic ecosystem behaviour refer to the following modelled system active processes (as listed in Figure 1.6 The DDBR system QR model Scenarios names, and described in subsection 1.6.1 Scenario description):

Scenarios concerning the aquatic Plant growth process for different initial values of Nutrient inflow in the modelled system:

- Sce01 Diatoms growth process to low Nutrient inflow
- Sce02 Diatoms growth process to medium Nutrient inflow
- Sce03 Diatoms growth process to high Nutrient inflow
- Sce04 Blue-green algae growth process to medium Nutrient inflow
- Sce05 Blue-green algae growth process to high Nutrient inflow.

From the five Scenarios constructed to model the aquatic *Plant* growth process, the simulation results are presented for two of them, as follows:
Scenario Sce01 *Diatoms* growth process to Low Nutrient inflow (Figure 2.1);
Scenario Sce05 *Blue-green algae* growth process to High Nutrient inflow (Figure 2.2).

These two *Plant* species are separately modelled as they have different behaviour for the same Environment conditions, and different roles within the Functional Feeding Groups: *Diatoms* (microscopic algae) are food resource for many aquatic species, especially for Zooplankton (See the process MF “Zooplankton growth process”, Figure 1.7.28), instead *Blue-green algae* (bacteria species) are (most of them) water poisoning species, especially due to Cyanotoxins (released in water as result of POM bacterial decomposition process) thus “contributing” to Water pollution process, and to Aquatic population: Mortality, implicitly (See the process MF “Blue green algae and cyanotoxins”, Figure 1.7.27).
As Aquatic macrophytes have the same behaviour as Blue-green algae, there is not constructed a scenario for this Plant species, too.

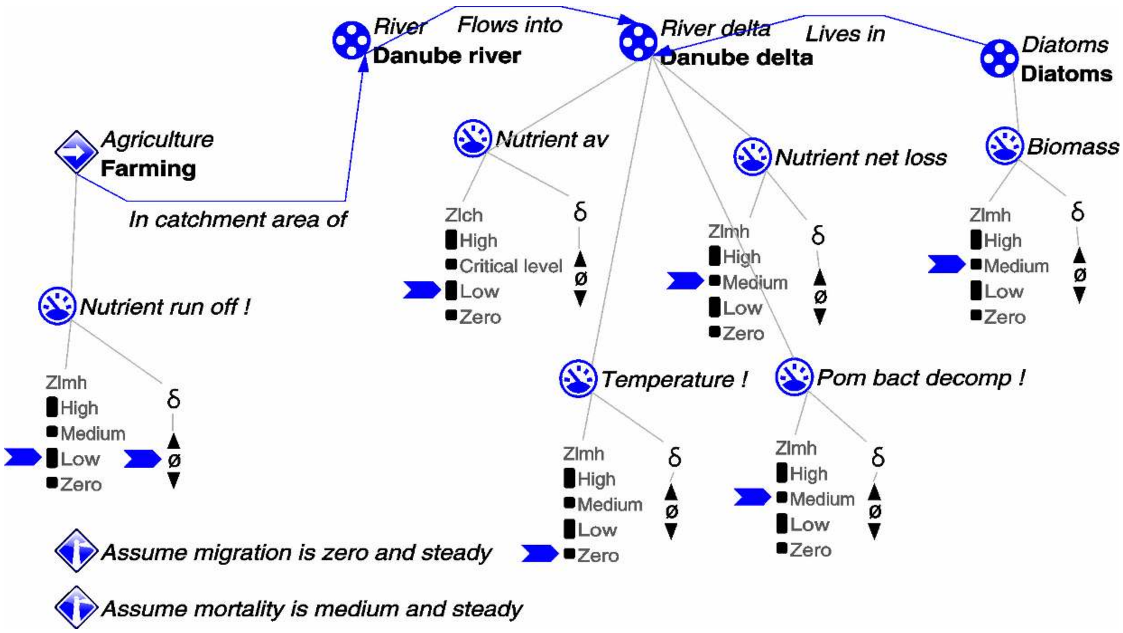


Figure 2.1 Sce01 Diatoms growth process to Low Nutrient inflow Scenario.

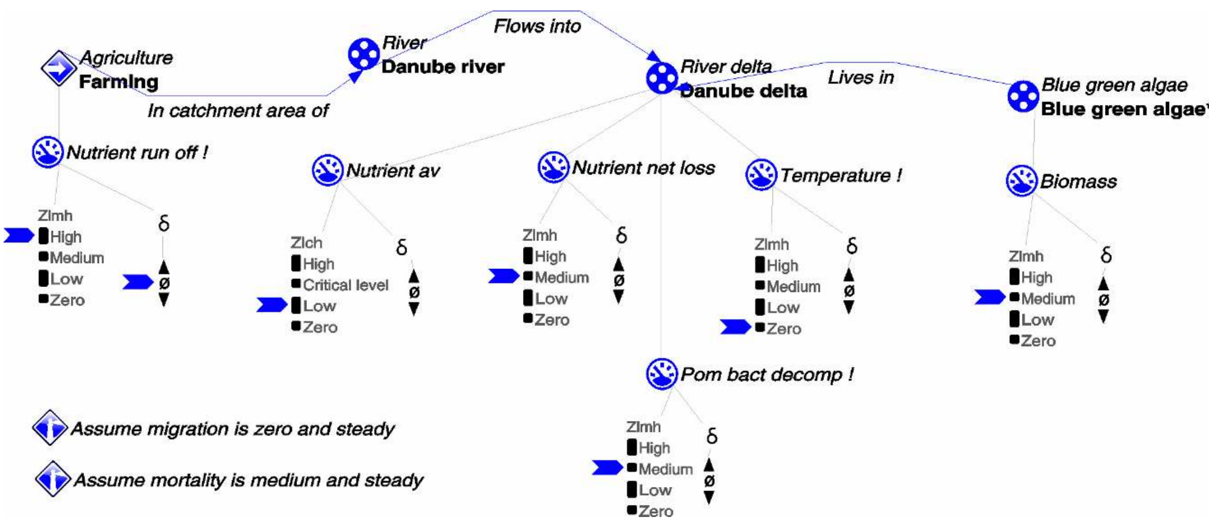


Figure 2.2 Sce05 Blue-green algae growth process to High Nutrient inflow Scenario.

2.2. Begin states

Begin states in Scenarios concerning the aquatic Plant growth process for different initial values of Nutrient inflow in the modelled system:
Begin and end-states in Scenario Sce01 Diatoms growth process to Low Nutrient inflow;
Begin and end-states in Scenario Sce05 Blue-green algae growth process to High Nutrient inflow.

The two Scenarios modelled the aquatic Plant species growth process for two different food resource (Nutrient) conditions.

Thus, within these two Scenarios, Sce01/Sce05 the same **initial values** are assigned for all quantities, excepting the Agriculture: Nutrient run-off, as follows:
Agriculture: Nutrient run-off: Low/Constant, and High/Constant, respectively.
Diatoms / Blue green algae: Biomass: Medium/None
River delta: Nutrient available: Low/None; Nutrient net loss: Medium/None; Temperature: Zero/Increase, Pom bacterial decomposition: Medium/Steady.
In these initial conditions of the *Plant* growth process, the same 4 initial states are generated (for each of the two scenarios), as described in Table 2.1, and shown in Figure 2.3 (The state-graph of Initial states).

2.2.1. Begin states definition

Within aquatic ecosystems, in the framework of any Plant growth process, the main water quantities that trigger this process are: water Nutrient concentration, and water Temperature.

In these ecosystems, when Agriculture: Nutrient run-off (as Agent) is **Low** (**Medium, or High**), so is the River and River Delta: Nutrient inflow.

Thus, three different conditions for water Nutrient concentration can exist, because its value can be **Low, Medium**, or **High**.
The process starts when water Nutrient concentration is at least Low, 0. The value Zero never occurs because a river or lake ecosystem water Nutrient concentration has two main resources: an outside (as Nutrient inflow) and an in-stream one (based on in-stream physical, chemical and biological processes). That's why the lowest possible value for water Nutrient is Low, -, when the process can stop.

The water Nutrient has different forms as result of aquatic physical, chemical and biological processes, such as:

1. *Nutrient inflow* – the Nutrient quantity that enters the system from an outside resource.
2. *Nutrient consumption* – the Nutrient quantity consumed by Plant and influenced by the Plant: Biomass quantity. Nutrient consumption can be Zero if the Biomass is Zero.
3. *Nutrient available* - the Nutrient quantity that assures the Plant: Production.
4. *Nutrient outflow* - the Nutrient quantity that leaves the system.
5. *Nutrient net loss*- the Nutrient quantity that is "lost" in the system both as Plant Nutrient consumption and Nutrient outflow. So, an important quantity of Nutrient is lost this way. But, by Particulate organic matter bacterial decomposition (a biological process) a significant quantity of Nutrient is released (recycled) in water column, diminishing the Nutrient net loss.
6. *Nutrient build-up rate* - the Nutrient quantity that has a direct positive influence on Nutrient available. Never is Zero. Nutrient build-up rate is indirect positively influenced by Nutrient inflow and negatively by Nutrient net loss. So, this quantity value has the greatest variability being indirectly both positively and negatively influenced by Nutrient inflow, Nutrient consumption, Nutrient outflow, and Particulate organic matter bacterial decomposition.

That's why this quantity is responsible for differentiating the initial states in any Plant growth process Scenario Simulation.

The water Temperature can influence the quantities involved in Plant growth process when is equal or higher than Zero. At water Temperature Zero, +, the process starts, and Plant die when Temperature is High, +, meaning the end of the process.

The same **4 initial states** are generated for any aquatic *Plant* growth process by Scenario Simulation, even if it starts from a different value for *Nutrient inflow*: **Low, Medium**, or **High**.
They are determined by the 4 possible initial values of *River Delta*: *Nutrient build up rate* (**Plus, +**; **Plus, 0**; **Plus, -**; **Minus, -**), as responsible to start the process within one of the following initial conditions:

1. Agriculture: Nutrient run-off can be **Low/ Constant** (Sce01), **Medium/ Constant** (Sce02 and Sce04) or **High/ Constant** (Sce03 and Sce05).

2. River Delta: Nutrient available **Low/None** (Sce01÷ Sce05);
3. Nutrient net loss: **Medium/None**(Sce01÷ Sce05);
4. Pom bacterial decomposition: **Medium/Steady**(Sce01÷ Sce05);
5. Temperature: **Zero/Increase** (Sce01÷ Sce05), and
6. Diatoms: Biomass **Medium/None** (Sce0÷ Sce05).

The 4 initial states have the same content for all five Scenarios. The only difference among Scenarios is given by the *Agriculture*: *Nutrient run-off* (and by *River* and *River Delta*: *Nutrient inflow* implicitly) value which is Low in Sce01, Medium in Sce02 and Sce04, and High in Sce03 and Sce05.

These initial quantity values which trigger changes on quantity values involved in any aquatic *Plant* growth process are presented in Table 2.1, and in Dependency diagrams of initial states (Figures 2.6 and 2.7).

2.2.2. Quantities and quantity values

Table 2.1 Quantities and quantity values of the 4 Initial states for Scenarios related to aquatic Plant growth process.

Quantity	Sce01 Diatoms growth process to Low Nutrient inflow Quantity values	Sce05 Blue-green algae growth process to High Nutrient inflow Quantity values
River delta: Nutrient available	L,+; L,+; L,+; L, -	same
River delta: Nutrient build up rate	P,+; P,0; P,-; Minus,+	same
River delta: Nutrient consumption	M,-; M,-; M,-; M,-	same
River delta: Nutrient inflow	L,0; L,0; L,0; L,0	H,0; H,0; H,0; H,0
River delta: Nutrient net loss	M,-; M,0; M,+; M,-	same
River delta: Nutrient outflow	L,+; L,+; L,+; L, -	same
River delta: Pom bact decomposition	M,0; M,0; M,0; M,0	same
River delta: Temperature	Z,+; Z+; Z,+; Z,+	same
River: Nutrient inflow	L,0; L,0; L,0; L,0	H,0; H,0; H,0; H,0
Diatoms: Biomass	M,-; M,-; M,-; M,-	same
Diatoms: Growth	Minus,+; Minus,+; Minus,+; Minus,-	same
Diatoms: Migration	Z,0; Z0; Z,0; Z,0	same
Diatoms: Mortality	M,0; M,0; M,0; M,0	same
Diatoms: Production	L,+; L,+; L,+; L, -	same
Agriculture: Nutrient run-off	L,0; L,0; L,0; L,0	H,0; H,0; H,0; H,0

2.2.3. State-graph

By Scenario simulation a number of 4 initial states result. Initial state-graph is presented in Figure 2.3.

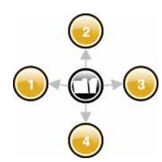


Figure 2.3 Sce01/Sce05: The state-graph of Initial states.

As one can notice the quantity values of the 4 Initial states (Table 2.1), the feedback to initial quantity values is given by: *River delta*: *Nutrient available* (which has the first 3 values L,+, and the last one L,-), *Nutrient Build-up rate* (which has 4 different values), *Nutrient net loss*

(which has 3 different values), *Nutrient outflow* and *Production* (which have the same behaviour as *Nutrient available*); *Diatoms* (or *Blue-green algae*): *Growth* (which has the first 3 values Minus,+, and the last, Minus,-: , as the same behaviour as *Nutrient available*).

2.2.4. Equation history

Equation history of initial states shows inequalities between some system component quantity values, those quantities able to start the process, as follows:

1. *Diatoms*: *Biomass* > Zero
2. *River Delta*: *Nutrient available* > Zero
3. *River Delta*: *Nutrient available > Nutrient net loss, within first 3 states and < within the last one*
4. *Diatoms*: *Production < Mortality*
5. *River Delta*: *Temperature >=Zero within all initial states.*

Biomass (Diatoms) ? Zero

>	>	>	>
1	2	3	4

Nutrient av (Danube delta) ? Zero

>	>	>	>
1	2	3	4

Nutrient inflow (Danube delta) ? Nutrient net loss (Danube delta)

>	>	>	<
1	2	3	4

Production (Diatoms) ? Mortality (Diatoms)

<	<	<	<
1	2	3	4

Temperature (Danube delta) ? Zero

>=	>=	>=	>=
1	2	3	4

Figure 2.4 Sce01/Sce05: Equation history of Initial states.

2.2.5. Value history graphs

Information on the 4 initial states quantities and quantity values is provided in the Value history graphs (Figure 2.5), as described in Table 2.1.

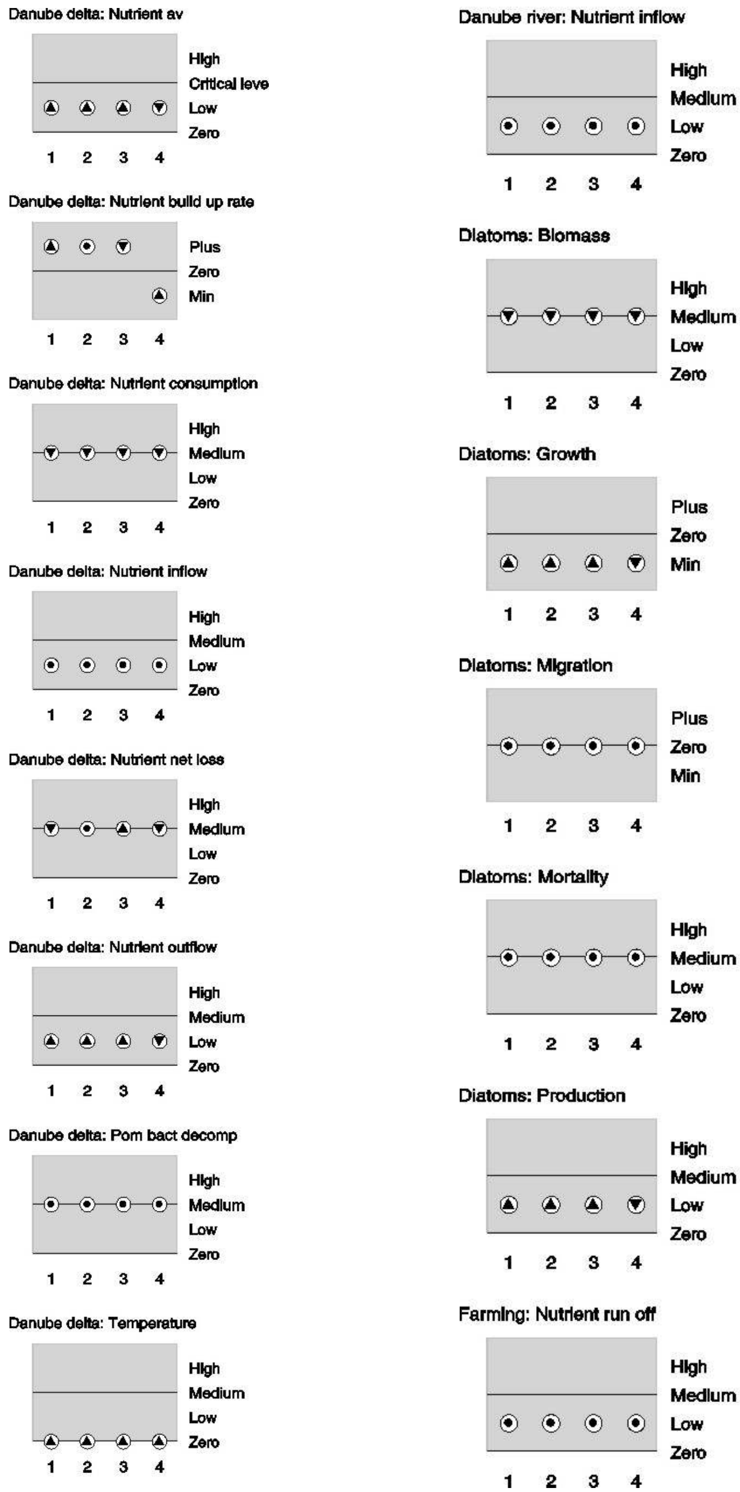


Figure 2.5 Sce01 Quantities and quantity values of the 4 Initial states: Value history graph.

2.2.6. Dependency diagrams

Dependency diagrams of initial states show initial values of quantities and how they are interrelated (Figures 2.6 and 2.7). Two of the possible start conditions are shown in Figure 2.6 and 2.7.

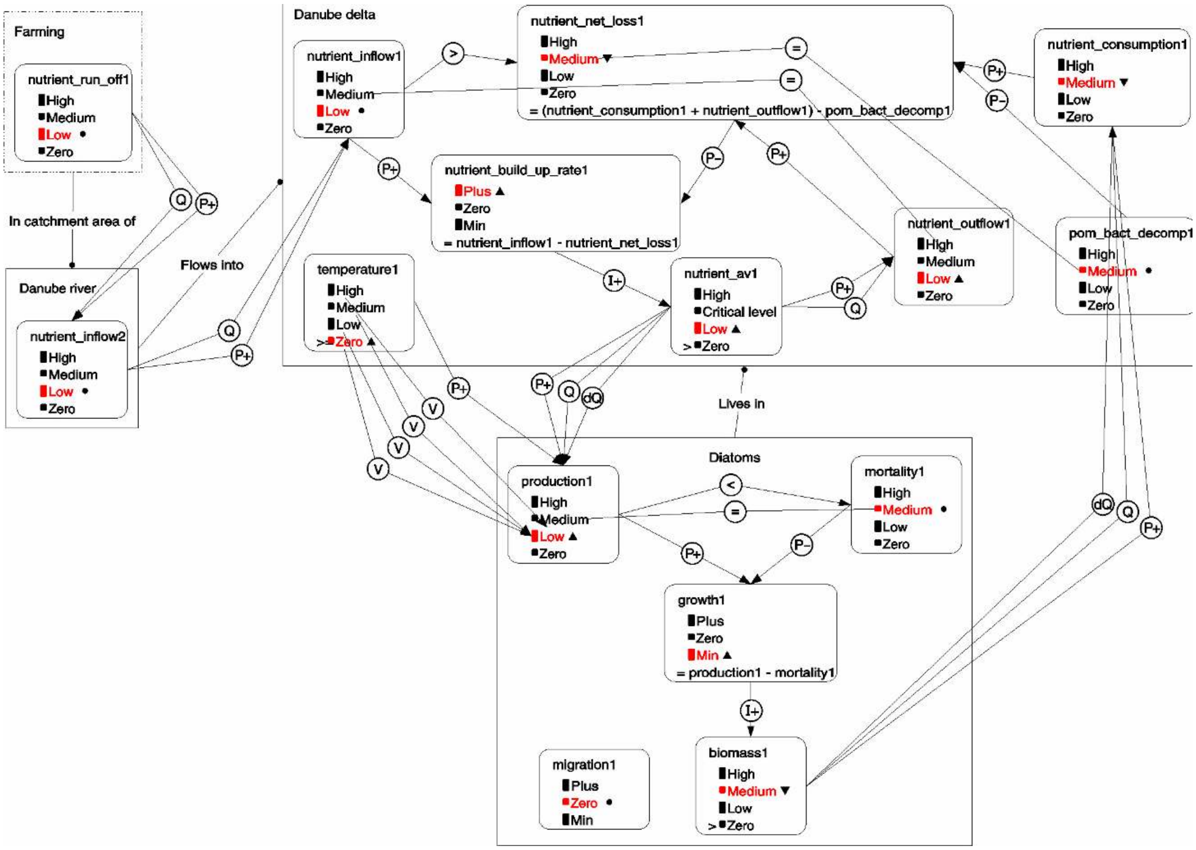


Figure 2.6 Sce01/Sce05: Dependency diagram of Initial state 1.

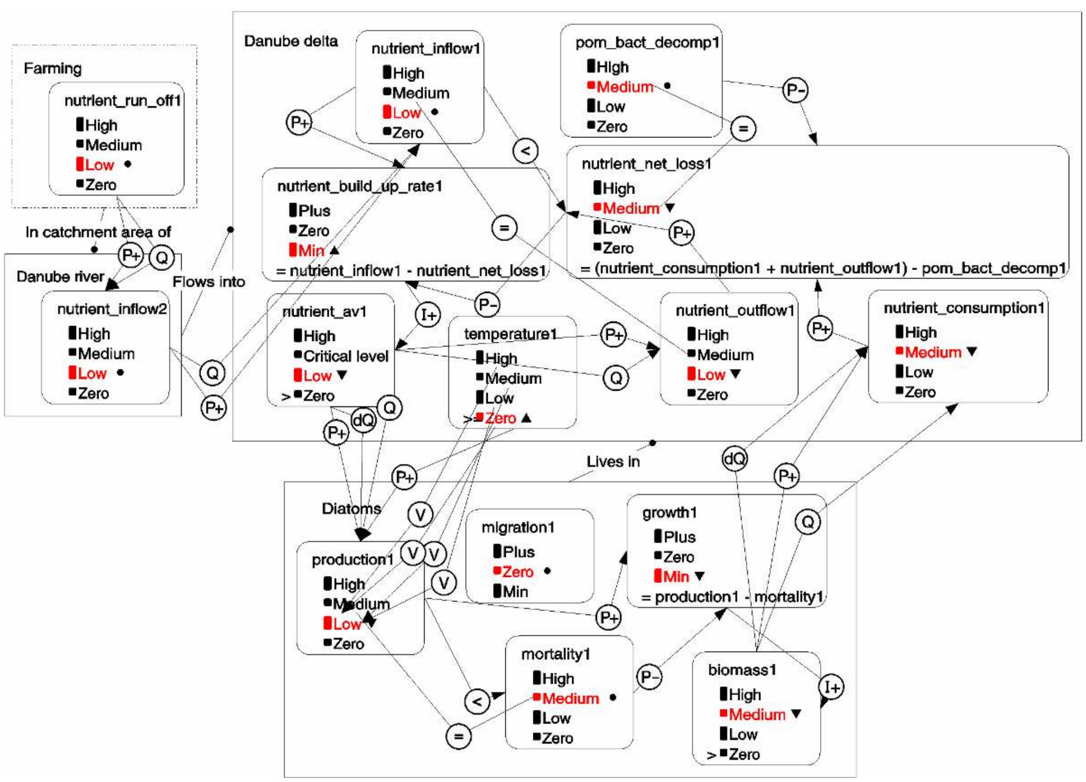


Figure 2.7 Sce01/Sce05: Dependency diagram of initial State 4.

2.3. State-graphs

All states generated by full simulation, starting from the 4 initial states, are presented in Figures 2.8, and 2.9, for Sce01, and Sce05, respectively. In these Figures the global state-graph is shown and initial and end-states are selected (red coloured).

By full simulation of Sce01, the 4 initial states (1, 2, 3, and 4) generate a total number of 44 states. Two of them are end-states: 25 and 42.

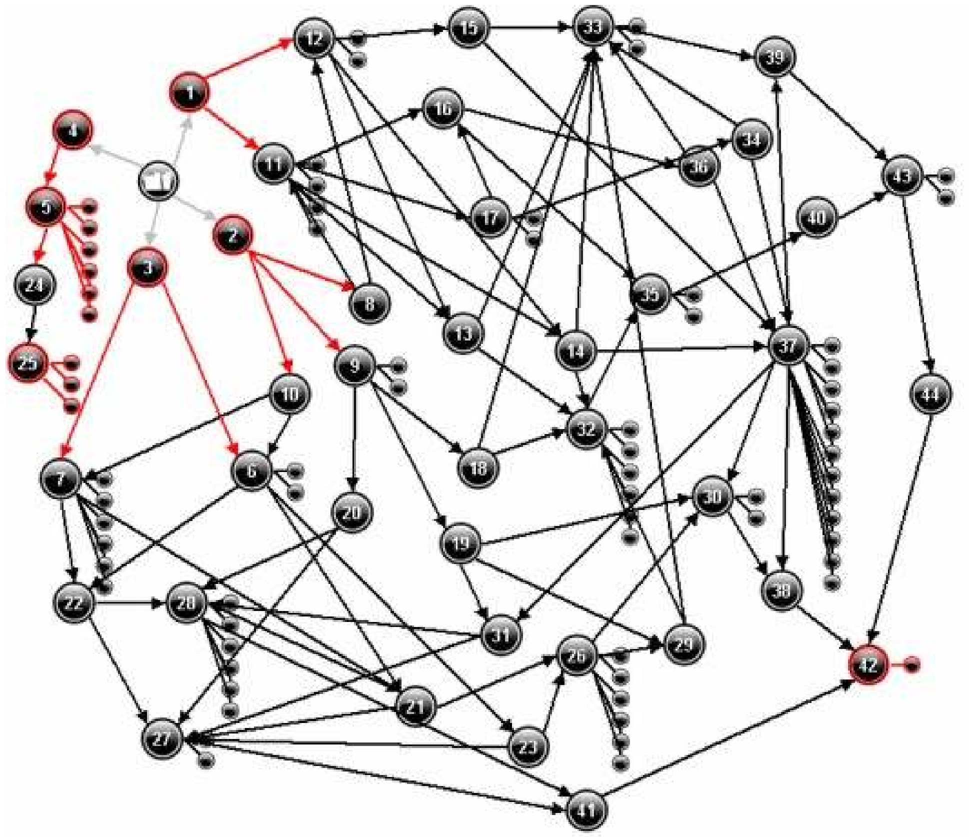


Figure 2.8 Sce01 Diatoms to low Nutrient inflow – State-graph.

I. 4 initial states: 1, 2, 3, and 4 (red coloured).
II. Full simulation states: 44 states.
III. 2 end states: 25 and 42 (red coloured).

By full simulation of Sce05, the same 4 initial states as in Sce01 (1, 2, 3, and 4) generate a total number of 33 states. Three of them are end-states: 5, 21 and 31 (Figure 2.9).

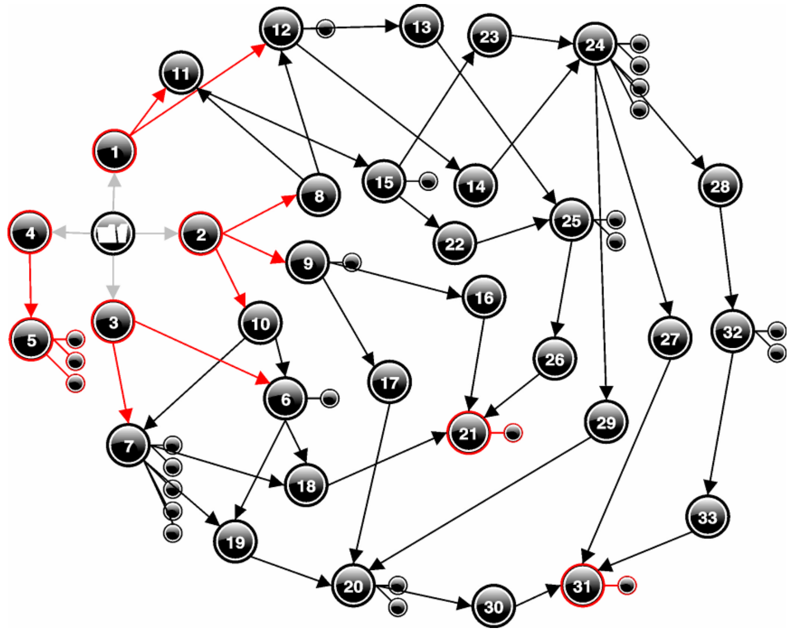


Figure 2.9 Sce05 Blue-green algae to High Nutrient inflow - State-graph:
I. 4 initial states: 1, 2, 3, and 4 (red coloured)
II. Full simulation states: 33
III. 3 end states: 5, 21, and 31 (red coloured).

2.4. End-states

2.4.1. End- states definition

End-states define the extreme possible quantity values which all quantities (those “responsible” for generating changes on other quantities) can reach them in the same time. From an end-state, these quantities can not change / generate any possible change on other quantities. So, an end-state is the limit (either the highest, or the lowest) the system can reach it, based on those extreme values the quantities can reach. Thus, an end-state show the conditions when a process stops. Within a state-graph an end-state ends one or more paths of states.

2.4.2. End-states in Sce01

The end-state 25 ends the only path of states generated from initial state 4 (see Figure 2.8 Sce01 State-graph). State 4 is the only initial state with Low, - value for *River delta: Nutrient available* (See Figure 2.10). For the other three initial states [1, 2, 3], this value is Low, +. In end-state 25: extreme value Low, - is reached by *River delta*: *Nutrient available*, *Nutrient net loss*, and *Diatoms*: *Production*; and the other extreme value High, + is reached by *Water*: *Temperature*. In natural aquatic ecosystems, Nutrient never reaches Zero. That’s why, Low, - is an extreme value that *River delta*: *Nutrient available* for Plant growth can reach it and can stop the process.

The end-state 42 ends all path of states generated from initial states 1, 2, and 3. In end-state 42, extreme value High, + is reached by *River delta*: *Nutrient net loss*, and *Temperature*, and Zero, 0 is reached by *Diatoms*: *Biomass*, and Biomass is Zero, 0 regardless of *Diatoms*: *Production* and *Diatoms*: *Mortality*, because in this state are active (see Figure 2.11 the MFs “*Growth by migration only*: *Diatoms*”, where Migration is Zero/Steady, “*Assume migration is zero and steady*: *Diatoms*”, and “*Population none existing*: *Diatoms*”. Also, *Water*: *Temperature* is High, +. All these extreme quantity values can stop the process.

2.4.3. Quantities and quantity values in Sce01

Quantities and their values of the two end-states 25 and 42 of Sce01 state-graph are presented in Figure 2.10.

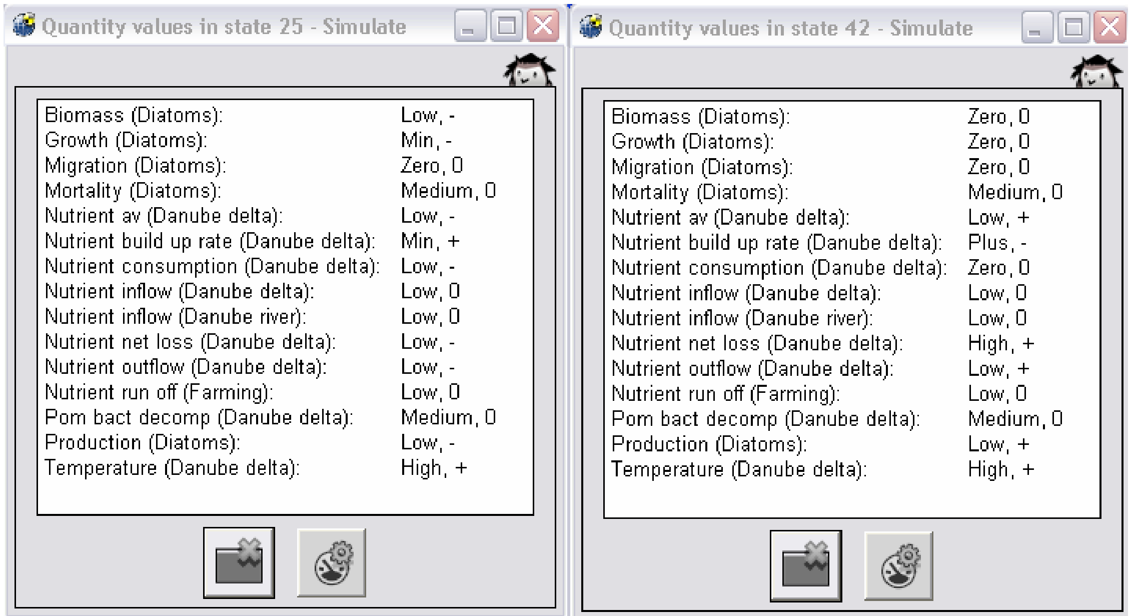


Figure 2.10 Sce01: End states 25 and 42 Quantities and Quantity values.

For end-state 25 the process is stopped as result of two extreme quantity values: *River delta*: *Nutrient available* Low, - and *Water*: *Temperature* High, +.
For end-state 42 the process is stopped as result of three extreme quantity values: *Diatoms*: *Biomass Zero*, 0, *River delta*: *Nutrient net loss* High, +, *Water*: *Temperature* High, +.

2.4.4. Active MFs in initial and end states in Sce01

The active Model fragments in Sce01 initial and end-states are as listed in Figure 2.11. For initial state 1 (2 and 3, too) and end-state 25, same MFs are active. Instead, in end-state 42, "*Growth by migration only*" MF (where *Migration* is assumed Zero/Steady) and "*Population none existing*" MF (where *Biomass* is equal Zero) are active, regardless of the *Diatoms*: *Production* and *Mortality* quantity values. That conditions end the process.

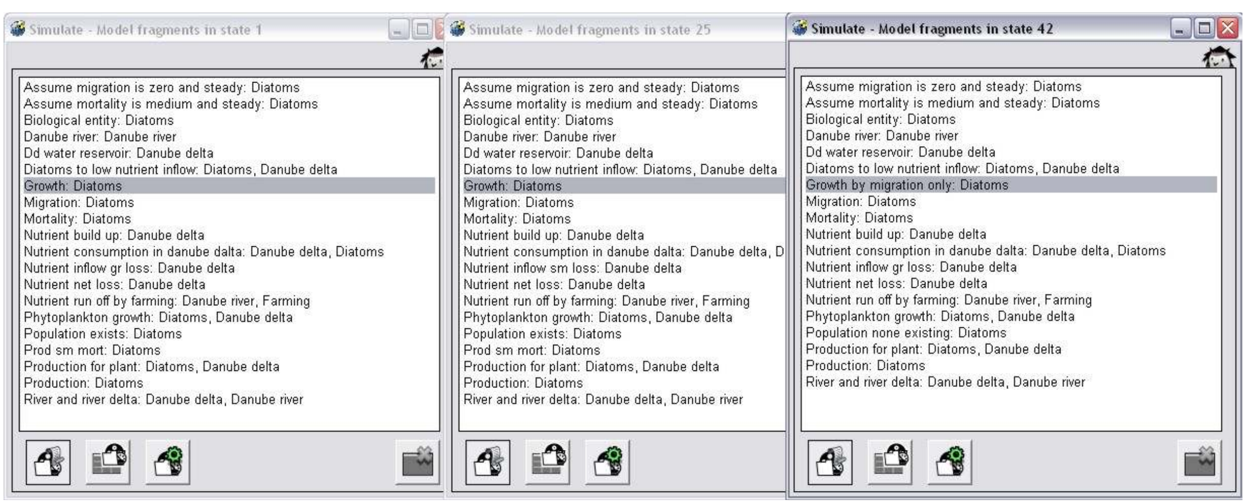


Figure 2.11 Sce01 Active MFs within initial state 1 and the two end states 25 and 42.

2.4.5. End-states in Sce05

In Sce05 the end-states are 5, 21, and 31 (see Figure 2.9 Sce05 State-graph). They define the end of the Plant growth process as result of the lowest possible value for *Nutrient available*: Low, - , which occurs in end-state 5. The same behaviour takes place in end-state 25 in Sce01. That can stop the *Plant* growth process (See the value history graph in Figure 2.12).

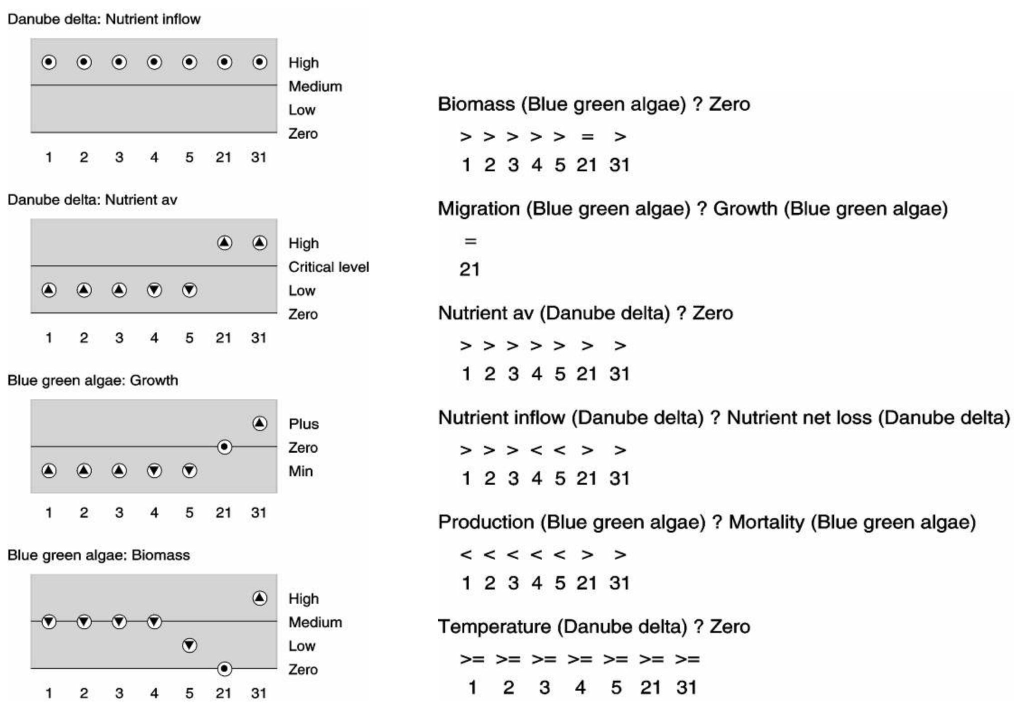


Figure 2.12 Sce05: Initial (1, 2, 3, and 4) and end-states (5, 21, and 31) value history diagram and equation history.

Zero, 0 value is reached by *Blue green algae*: *Biomass* in end-state 21. The behaviour of end-state 21 is similar to the one of end-state 42 in Sce01, when the *Blue green algae*: *Biomass*: is Zero, regardless of the *Blue green algae*: *Production* and *Blue green algae*: *Mortality*, because in this state are active (see Figure 2.13) the MFs "*Growth by migration only*: *Blue green algae*", when Migration is Zero/Steady, "*Assume migration is zero and steady*", and "*Population none existing*: *Blue green algae*", and the Dependency diagram of state 21 (Figure 2.14). Also, *Water*: *Temperature* is High, +. All these extreme quantity values can stop the process.

2.4.6. Active MFs in initial and end states – Sce05

The active Model fragments in Sce05 initial and end-states are as listed in Figure 2.13. For initial state 1 and end-state 5 and 31 same MFs are active. Instead, in end-state 21, "*Growth by migration only*" MF (where *Migration* is assumed Zero/Steady) and "*Population none existing*" (where *Biomass* is equal Zero) MFs are active. That conditions end the process.

Figure 2.13 Sce05: Active MFs in initial state 1 and the three end-states 5, 21, and 31

2.4.7. Dependency diagrams of end-states in Sce05

Most of quantities are at their extreme value: Zero, 0 (for Biomass in state 21, Figure 2.14), or High, + (in end-state 31, Figure 2.15). All extreme quantity values, especially the *Water*: *Temperature* can stop the process.

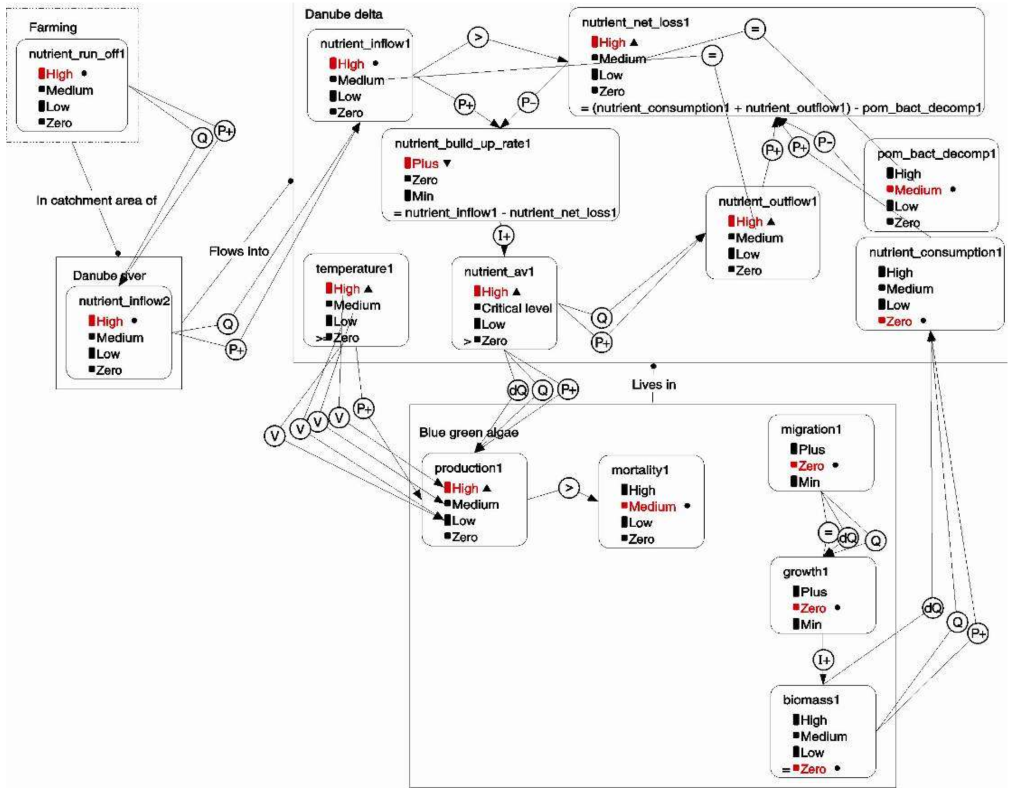


Figure 2.14 Sce05: Dependency diagram of end-state 21: Plant growth based on Migration only: Migration is Zero/Steady.

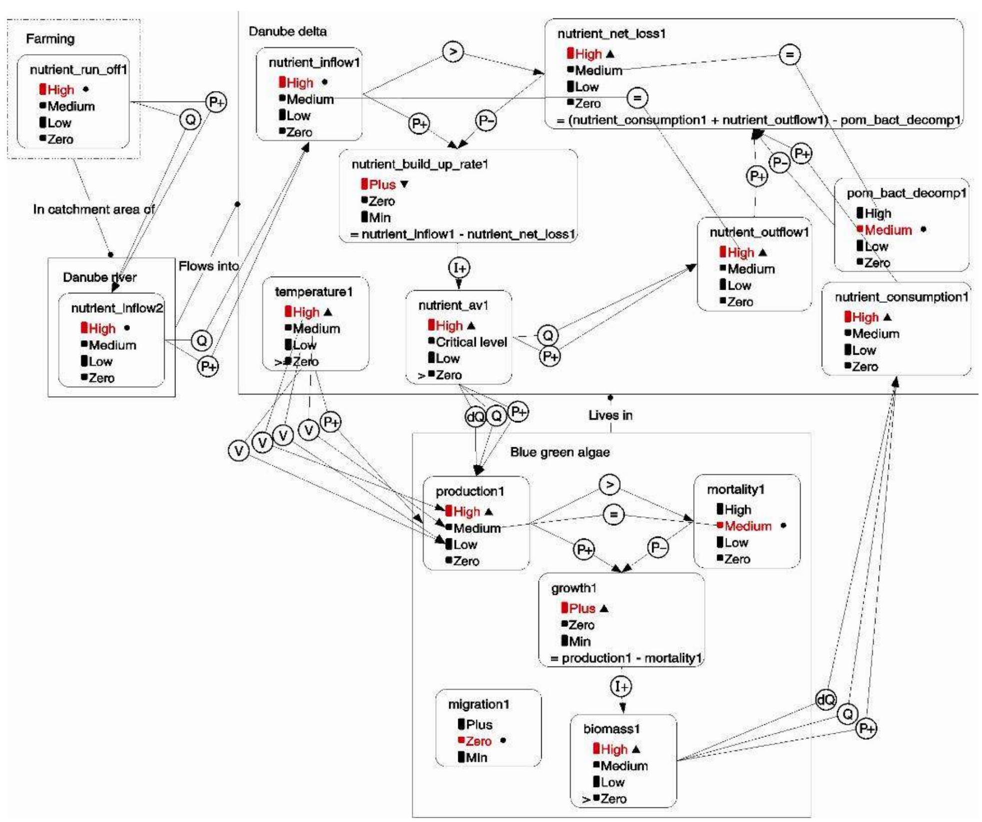


Figure 2.15 Sce05: Dependency diagram of end-state 31.

2.5. Behaviour paths

2.5.1. Global Behaviour paths of Sce01 state-graphs

In Sce01 state-graph all state-paths end with end-state 42, which results due to the particular condition for the Plant growth process based on Migration only, regardless of the Plant: Production and Mortality, and when Migration is Zero/Steady. So is the Diatom: Biomass, meaning the end of the process (the Plant extinction).

2.5.2. Value history graphs of global behaviour paths in Sce01

The Global view of Sce01 state-graph Value history shows the following system behaviour, as figured in Figure 2.16 (I) and 2.16 (II):

Danube delta: Nutrient available

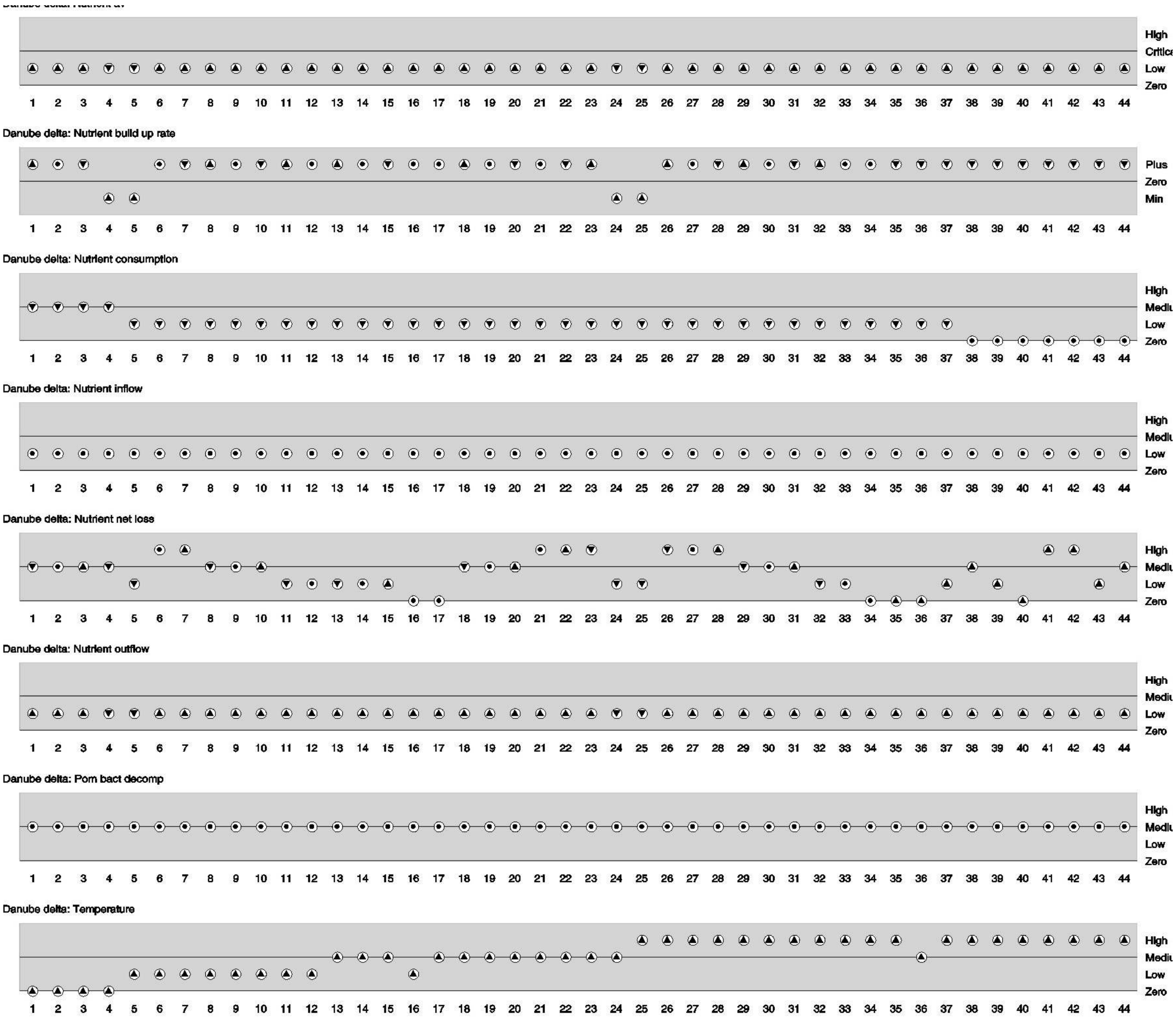


Figure 2.16 (I) Sce01: Value history diagrams of Global state-graphs.

1. *Agriculture*: *Nutrient run-off* is constantly Low / Constant. It is the condition necessary to study the system behaviour related to the aquatic Plant growth process, starting with Low content of Nutrient from the main source. (Agent: Agriculture zones). So is the
2. *River*: *Nutrient inflow*, and

3. *Danube delta*: *Nutrient inflow*.
4. *Danube delta*: *Nutrient available* is constantly Low, - in the only path of states [4→5→24→25] generated by the initial state [4]. So is the *Diatoms*: *Production* quantity.
5. *Danube delta*: *Nutrient available* is constantly Low, + in the other states generated by the initial states [1, 2, and 3], when *Diatoms*: *Production* is Low, +, too.
6. *Diatoms*: *Biomass* decreases constantly, from Medium, - (in states 1, 2, 3, 4) to Low, - (in states 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 ….37) to Zero, 0 (in states 38, 39, 40, 41, 42, 43, 44). *Diatoms*: *Biomass* is positively influenced (I+) by *Diatoms*: *Growth* process.

Figure 2.16 (II) Sce01 Global view of the Value history diagram.

7. *Danube delta*: *Nutrient Build up rate* and *Nutrient net loss* values have a great variability, either increasing, or decreasing in a sinusoidal shape in state-graphs. Both quantities are the result of complex physical, chemical, and biological processes.
8. *Danube delta*: *Temperature* values have a general tendency of increase from Zero, + →Low, + → Medium, + → High, +.

There is a strong relationship between water Temperature and the aquatic Plant: Production. The last one increases once with the water Temperature.

9. *Plant*: *Production* depends on *Water*: *Nutrient available* quantity very much, keeping the same values as Nutrient available, as there is a Functional Feeding relationship between them: Water: Nutrient available is the main food resource for any aquatic Plant species.
10. To reduce the simulation complexity, the quantities *Danube delta*: *Pom bacterial decomposition* and *Plant*: *Mortality* are assumed Medium/Steady, and *Plant*: *Migration* Zero/Steady.

2.6. Relevant behaviour paths in state-graphs- Sce01

One of the most relevant behaviour paths can be: [1→11→14→33→39→43→44→42], as selected in the state-graph of Sce01 (Figure 2.17).

The 42 state is the only end-state that ends all state paths generated by initial states (1, 2, and 3. As there is already described in the above subsection "**End-states in Sce01**", this end-state defines the *Diatoms*: *Biomass* extinction conditions: Low/Constant *River Delta*: *Nutrient inflow*, and the *Diatoms*: *Growth* based on *Diatoms*: *Migration* only, while Migration is assumed Zero/Steady.

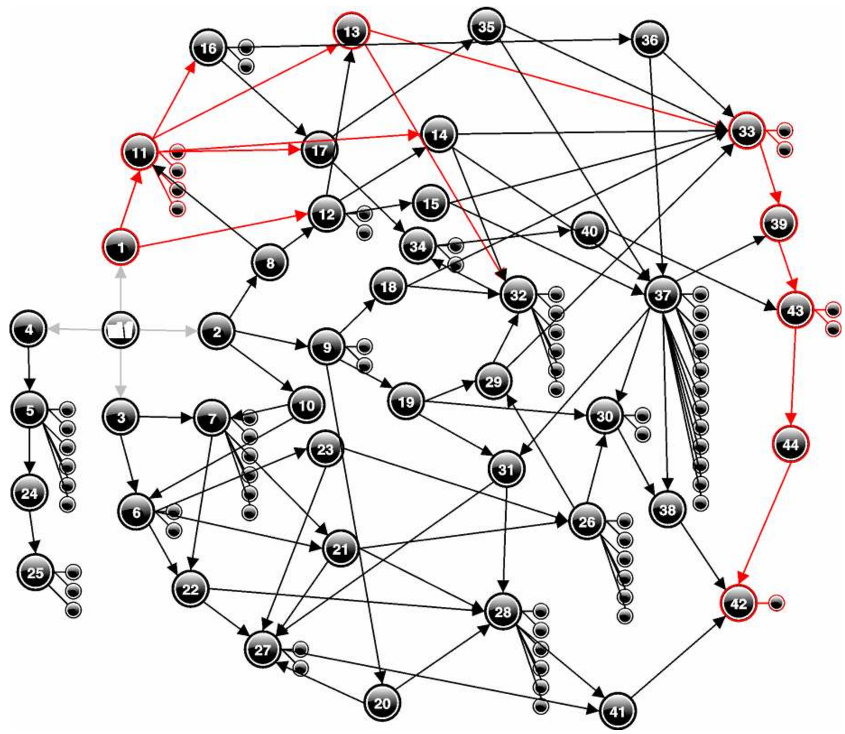


Figure 2.17 Sce01 behaviour path [1→11→13→33→39→43→44→42].

2.6.1. Equation history

Equation history of the relevant path of state [1→11→13→33→39→43→44→42] figures the system component behaviour by those quantity value changes which define the states that continue, or stop the process, as follows: starting from state 39 to 42, *Biomass* gets Zero as result of it's Growth based on Migration only (Migration is assumed Zero/Steady) regardless of the plant production and mortality value.

```
Biomass (Diatoms) ? Zero
  >  >  >  >  =  =  =  =
  1 11 13 33 39 43 44 42

Migration (Diatoms) ? Growth (Diatoms)
  =  =  =  =
  39 43 44 42

Nutrient av (Danube delta) ? Zero
  >  >  >  >  >  >  >  >
  1 11 13 33 39 43 44 42

Nutrient inflow (Danube delta) ? Nutrient net loss (Danube delta)
  >  >  >  >  >  >  >  >
  1 11 13 33 39 43 44 42

Production (Diatoms) ? Mortality (Diatoms)
  <  <  <  <  =  >  >  >
  1 11 13 33 39 43 44 42

Temperature (Danube delta) ? Zero
  >= >= >= >= >= >= >= >=
  1  11 13 33 39 43 44 42
```

Figure 2.18 Sce01 behaviour path [1→11→13→33→39→43→44→42]: Equation history.

2.6.2. Value history graphs

Same information on the system component behaviour is given by Value history graphs (Figure 2.19).

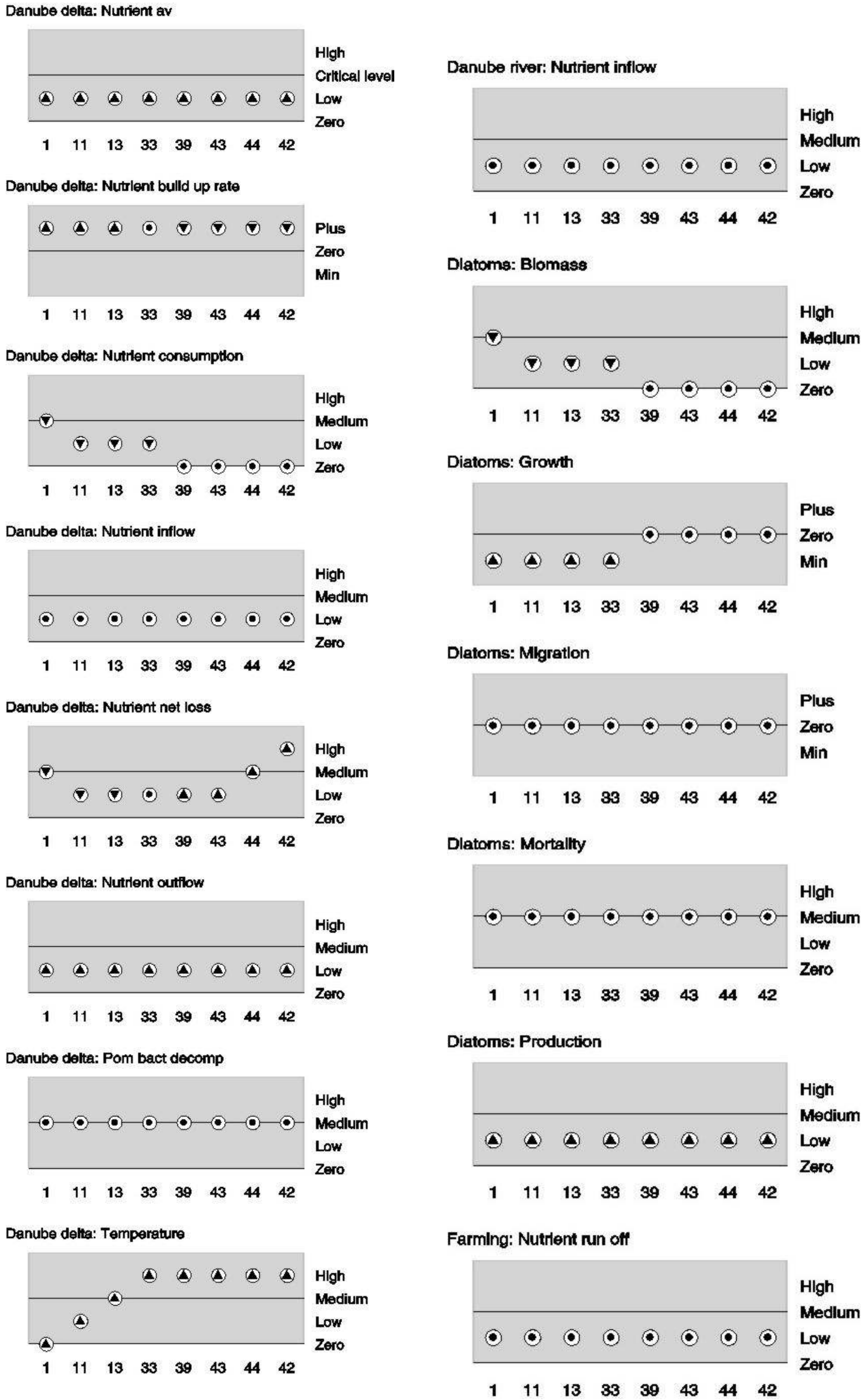


Figure 2.19 Sce01 behaviour path [1→11→13→33→39→43→44→42]: Value history.

The above two figures, 2.18 and 2.19, show the same general behaviour of the system, for *Danube Delta*: *Nutrient inflow* Low/Constant condition, as follows:

1. *Danube River*: *Nutrient inflow* is constantly Low, 0;
2. *Danube Delta*: *Nutrient available* is constantly Low, +;
3. *Danube Delta*: *Nutrient net loss* increases in the four last states [39→43→44→42], from Low, + to High, +.
4. *Danube Delta*: *Temperature* increases from Zero, + to High, + and stays at maximum value within last 5 states.
5. *Diatoms*: *Biomass* decreases from Medium, - to Low, -, in the first four states and becomes extinct (Zero, 0), in the four last states, as result of a Zero, 0 Diatoms: Growth. There are two possibilities for Growth to reach the value Zero, 0: either because *Diatoms*: *Mortality* equals *Diatoms*: *Production* (State 39, see Figure 2.18: Equation history) or due to the possible Growth condition based on *Diatoms*: *Migration* only (States 43→44→42). As long as *Migration* is assumed Zero/Steady, so is the Growth, and the Biomass, implicitly.

2.7. Behaviour paths in Sce05 state-graphs

2.7.1. Relevant behaviour path of states

One of the most relevant behaviour paths can be: [1→11→15→23→24→28→32→31], as selected in the state-graph of Sce05 (Figure 2.20).
The 31 state is one of the two end-states that ands all paths of states generated by the initial states 1, 2, and 3. This end-state is described in the above subsection "**End-states in Sce05**".
This behaviour state-path shows the other one possible extreme condition of the system behaviour when most of quantities are at their extreme value, High, +.

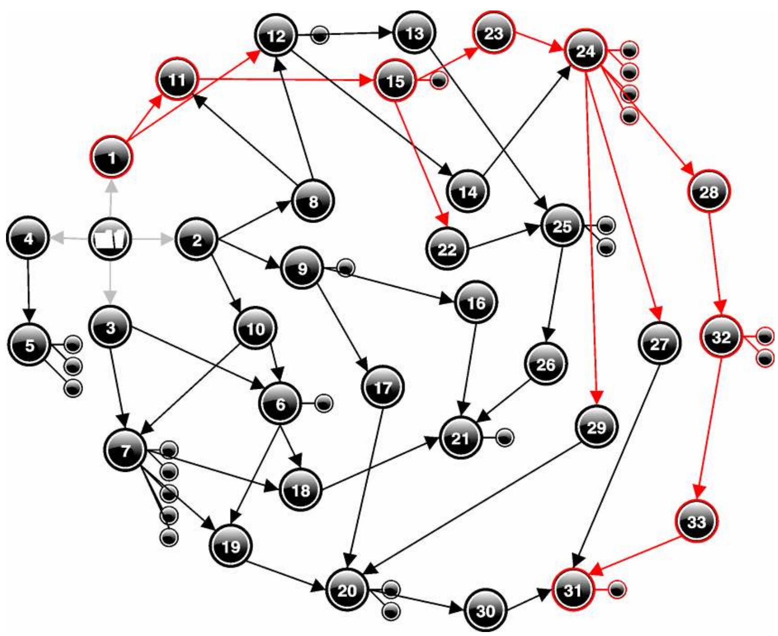


Figure 2.20 Sce05: behaviour path [1→11→15→23→24→28→32→33→31].

2.7.2. Equation history

Next 2 figures, 2.21, and 2.22, show the system behaviour for the *Danube Delta*: *Nutrient inflow* High/Constant condition, as follows:

Biomass (Blue green algae) ? Zero

>	>	>	>	>	>	>	>	>
1	11	15	23	24	28	32	33	31

Nutrient av (Danube delta) ? Zero

>	>	>	>	>	>	>	>	>
1	11	15	23	24	28	32	33	31

Nutrient inflow (Danube delta) ? Nutrient net loss (Danube delta)

>	>	>	>	>	>	>	>	>
1	11	15	23	24	28	32	33	31

Production (Blue green algae) ? Mortality (Blue green algae)

<	<	<	=	>	>	>	>	>
1	11	15	23	24	28	32	33	31

Temperature (Danube delta) ? Zero

>=	>=	>=	>=	>=	>=	>=	>=	>=
1	11	15	23	24	28	32	33	31

Figure 2.21 Sce05 behaviour path [1→11→15→23→24→28→32→33→31]: Equation history

1. *Danube River*: *Nutrient inflow* is constantly High, 0;
2. *Danube Delta*: *Nutrient available* increases from Low, + to High, + and stays at this maximum possible value within the 5 last states: [24→28→32→33→31];
3. *Blue-green algae*: *Growth* increases from Minus, + to High, + and stays at this maximum value for the last 5 states;
4. *Blue-green algae*: *Biomass* has a continuously sinusoidal shape value, from Minus, - to High, +, increasing state by state and stays at this maximum value for the last 3 states: [32→33→31];
5. *Danube Delta*: *Temperature* increases continuously from Zero, + to High, + and stays at maximum value within last 5 states;

2.7.3. Value history

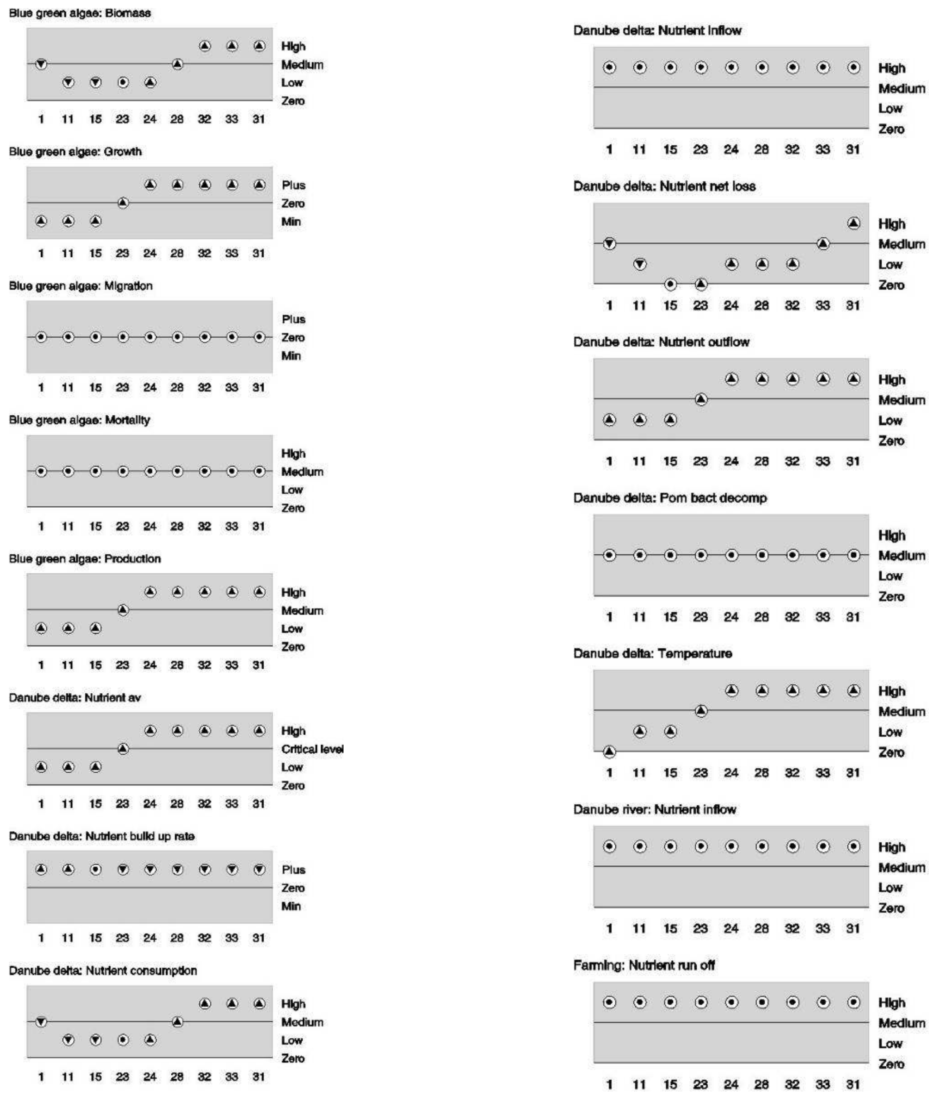


Figure 2.22 Sce05 behaviour path [1→11→15→23→24→28→32→33→31]: Value history.

Scenarios concerning the aquatic *Animal* growth process State graph

2.8. Scenarios

Four Scenarios have been constructed to model the aquatic *Animal* population growth process, in the framework of the Functional Feeding Group relationships. These are:

Sce06 Diatoms and Zooplankton growth process
Sce07 Zooplankton and Fish growth process
Sce08 Fish and Bird growth process
Sce09 Macrophytes and Macroinvertebrates growth process.

The four Scenarios are constructed on the same principle, as follows:

Two entities are considered in any Scenario, each of them with different role within the Functional Feeding Group relationship: predator and prey species, respectively.
The configuration is "Feeds on".
To reduce the simulation complexity, two Assumptions are introduced: "*Assume migration is zero and steady*" and "*Assume medium equality for production and mortality*", and they address both populations.
The initial situation of any aquatic *Animal* species (***Zooplankton***, ***Fish***, ***Bird*** or ***Macroinvertebrates***) growth process, regarding the *Quantity* values (Magnitude/Derivative) of the two *Entities* (*Aquatic populations*) involved in the process, can be:

For the predator species, the *Biomass*: Low/None, *Mortality*: Low/Constant;
For the prey species, the *Biomass*: Medium/None, the *Production*: Medium /Steady.

Within any *Animal* growth process, as there are Functional Feeding Group relationships among species, each *Animal* species can be both predator and prey.
The *Configuration*: "*Feeds on"* figures the functional feeding relationship between the two entities involved in the growth process.

From the four Scenarios constructed to model the aquatic *Animal* species behaviour, the simulation results are presented for one of them: Sce07 Zooplankton and Fish growth process (Figure 2.23 Sce07 Zooplankton and Fish growth process Scenario). All

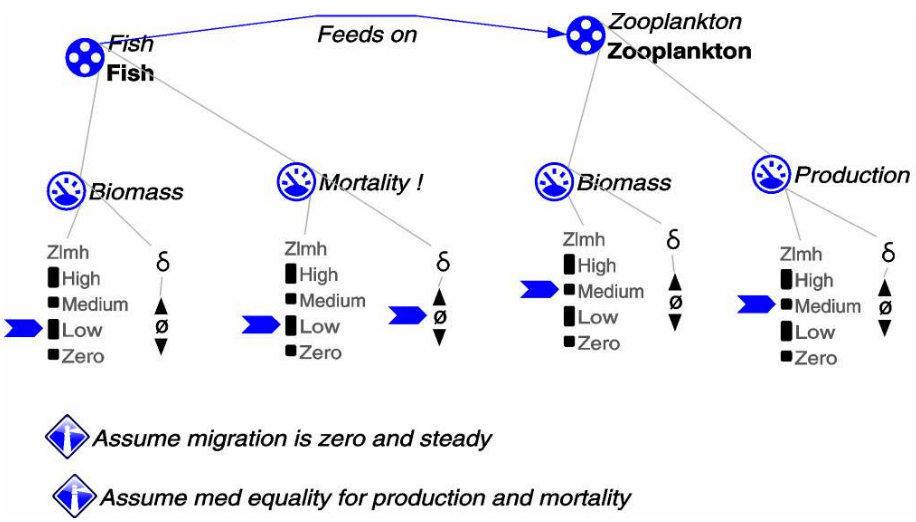


Figure 2.23 Sce07 Zooplankton and Fish growth process Scenario.

2.9. Begin states

Within aquatic ecosystems, in the framework of any *Animal* growth process, the main quantities that trigger this process are: *Predator*: *Production* > Zero, based on *Prey*: *Biomass*, > Zero.

State-graph of Initial states

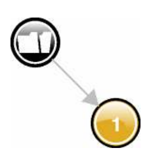


Figure 2.24 Sce07 Initial state graph.

A possible initial situation of any aquatic *Animal* species growth process, according to initial quantity values assigned in Scenario, can be:
Fish: *Biomass*: Low/None, *Mortality*: Low/Constant;
Zooplankton: *Biomass*: Medium/None, the *Production*: Medium /Steady.

2.9.1. Value history graphs

From the initial situation, 1 initial state resulted (Figure 2.24). The quantities and quantity value history of initial state is presented in Figure 2.25.

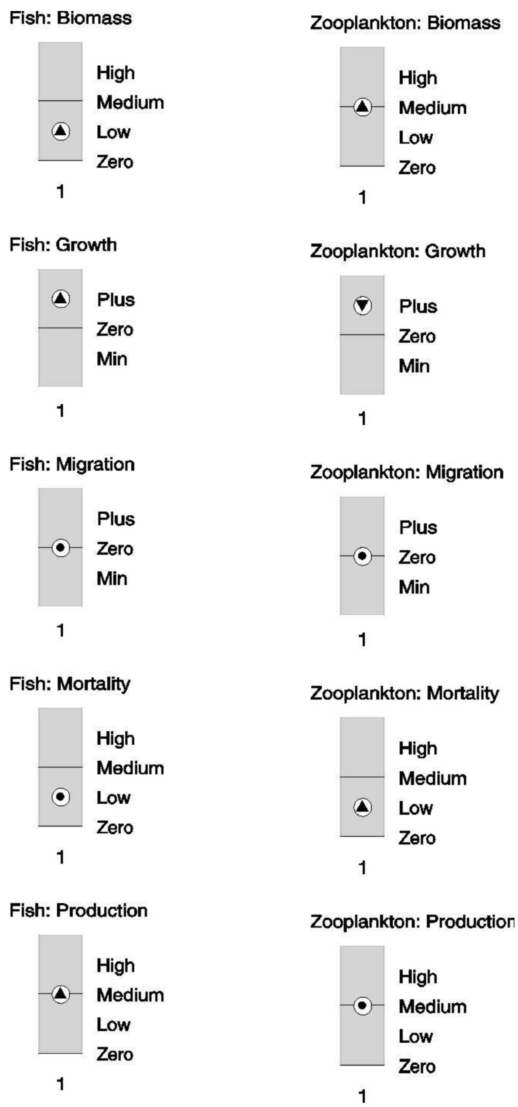


Figure 2.25 Sce07 Initial state value history.

It shows a possible condition for the process to start, from the two entities, quantities and quantity values (Magnitude/Derivative) point of view.

2.9.2. Equation history

Initial state equation history (Figure 2.26) shows a possible condition for the two populations to start the growth process.

Biomass (Fish) ? Zero
>
1

Biomass (Zooplankton) ? Zero
>
1

Production (Zooplankton) ? Mortality (Zooplankton)
>
1

Production (Fish) ? Mortality (Fish)
>
1

Figure 2.26 Sce07: Equation history of Initial state.

2.9.3. Dependency diagram

This diagram (Figure 2.27) provides information on causality relationship between two aquatic *Animal* populations, and the growth process start possible quantity values (as seen in Equation history, too):

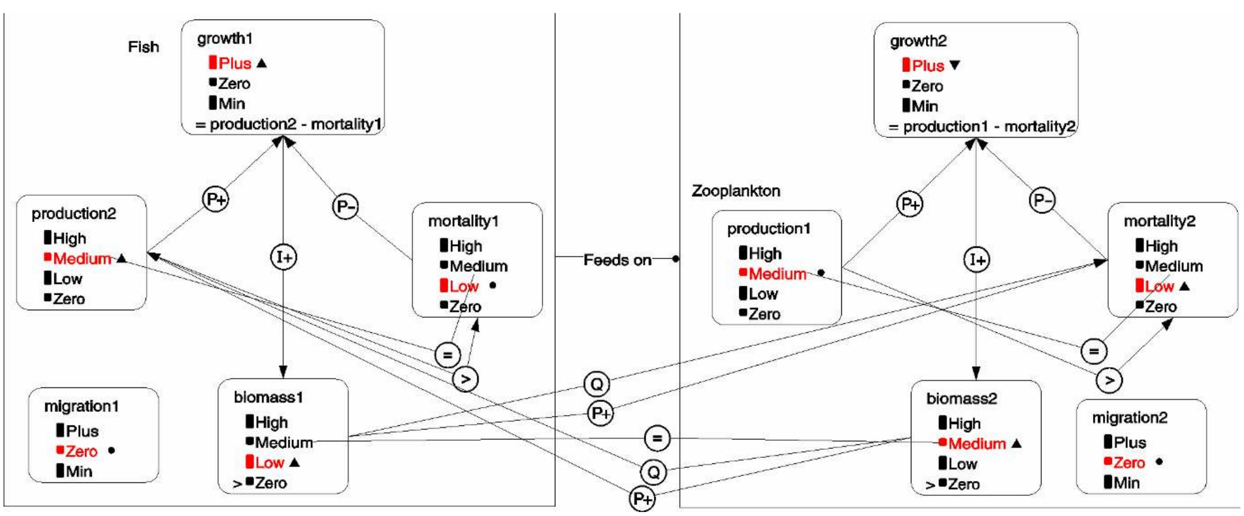


Figure 2.27 Sce07: Dependency diagram of Initial state 1.

Fish: *Production* > *Mortality*
Fish : *Biomass* > Zero
Zooplankton: *Production* > *Mortality*
Zooplankton: *Biomass* > Zero.

2.9.4. Active Model fragments

Model fragments that are active in initial state 1 are listed in Figure 2.28. They are related to the two aquatic animal populations, *Fish* and *Zooplankton* involved in their growth process.

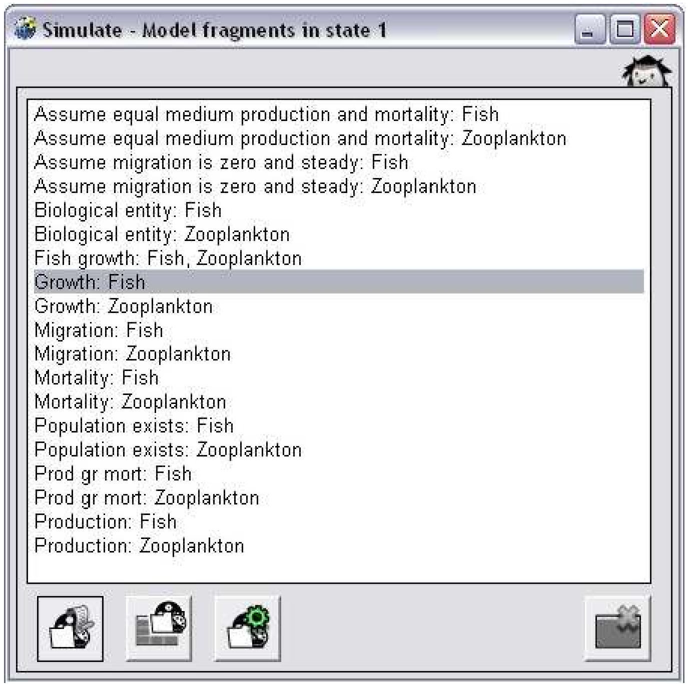


Figure 2.28 Sce07: Active Model fragments in Initial state 1.

2.10. State-graphs

All states generated by full simulation, starting from initial state, are presented in Figures 2.29. In this Figures the global state-graph is shown and initial and end-states are selected (red coloured). By full simulation of Sce07, the initial state 1 generates a total number of 20 states. Two of them are end-states: 12 and 20.

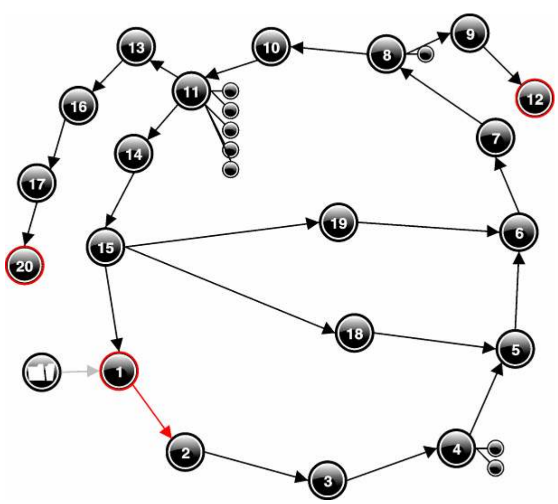


Figure 2.29 Sce07 Zooplankton and Fish growth process – State-graph.
I.1 initial states: 1 (red coloured).
II. Full simulation states: 20 states.
III. 2 end states: 12 and 20 (red coloured).

2.10.1. Value history graphs

Value history graphs show that the two system components involved in the modelled growth process has a continuity excepting those states when one of them (*Fish* or *Zooplankton*) gets Zero value for Biomass. Among these states (when Biomass is Zero), only one fulfils the end-state condition. These are

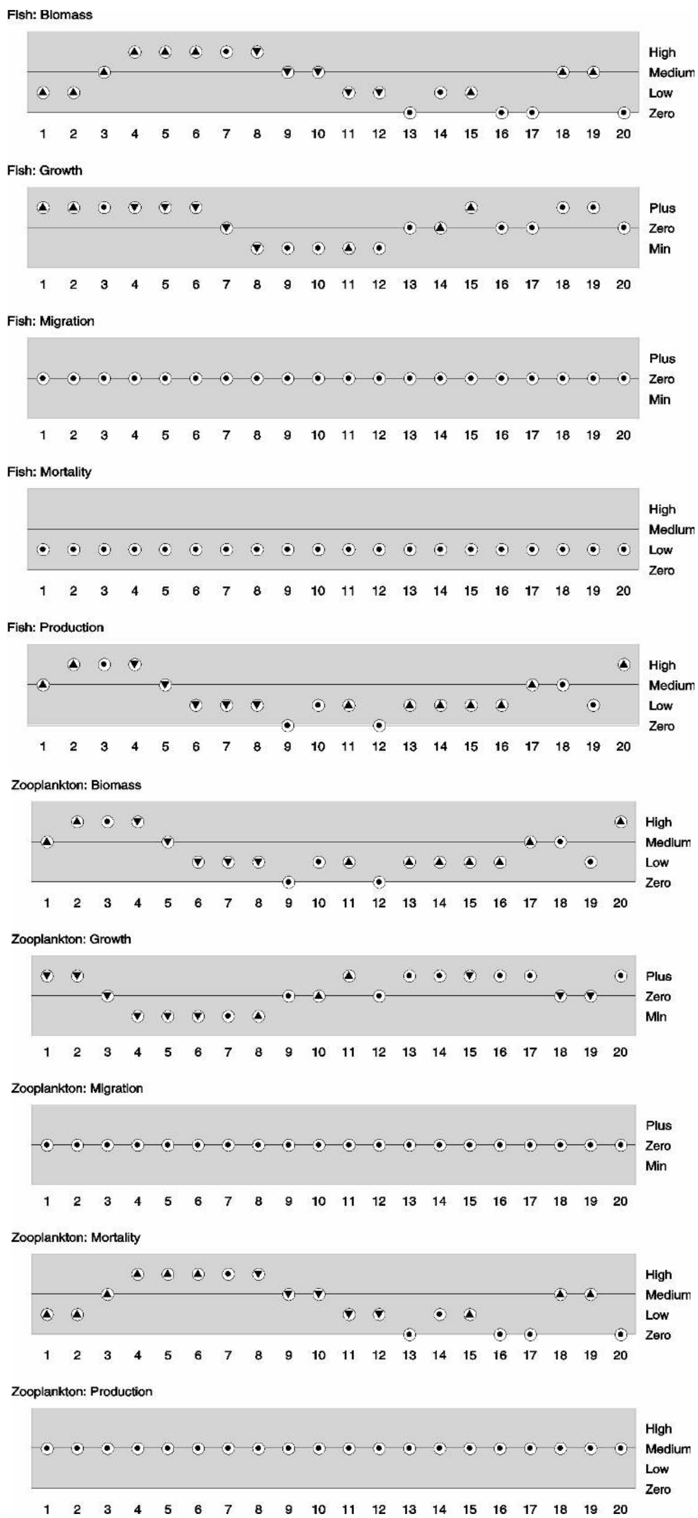


Figure 2.30 Sce07 Zooplankton and Fish growth process – Value history.

2.10.2. Equation history

From equation history, those states in which a *Population* (*Fish* or *Zooplankton*): *Biomass* is > or equals (=) Zero (meaning the population extinction) are:
Fish: *Biomass* > Zero within the path of states (see Figure 2.29 Sce07 Zooplankton and Fish growth process – State-graph) [1→2→3→4→5→6→7→8→9→10→11→12→14→15], including 18 and 19.

Biomass (Fish) ? Zero

>	>	>	>	>	>	>	>	>	>	>	>	=	>	>	=	=	>	>	=
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Biomass (Zooplankton) ? Zero

>	>	>	>	>	>	>	>	=	>	>	=	>	>	>	>	>	>	>	>
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Migration (Fish) ? Growth (Fish)

=	=	=	=
13	16	17	20

Migration (Zooplankton) ? Growth (Zooplankton)

=	=
9	12

Production (Zooplankton) ? Mortality (Zooplankton)

>	>	=	<	<	<	<	<	=	=	>	>	>	>	>	>	>	=	=	>
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Production (Fish) ? Mortality (Fish)

>	>	>	>	>	>	>	=	<	<	<	<	=	=	>	>	>	>	>	>
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Figure 2.31 Sce07 Zooplankton and Fish growth process – Equation history.

Fish: *Biomass* = Zero within the branch [13→16→17→20] as *Growth* of Fish is based on *Migration* only, and *Migration* is assumed Zero /Steady.
Zooplankton: *Biomass* = Zero within the branch [9→12], as *Growth* of *Zooplankton* is based on *Migration* only.
Only in two of these states, 12 (see Figure 2.23 Dependency diagram of end state 12) and 20 (see Figure 2.34 Dependency diagram of end state 20) are fulfilled those conditions of end-state that can stop the process. States 12 and 20 end the branches of states in which Growth is based on Migration only.

2.11. End-states

The end-states 12 and 20 define the two possible conditions when the *Prey (Zooplankton)*: *Biomass* and the *Predator (Fish)*: *Biomass*, respectively, gets Zero (meaning the extinction of that population). That happens when *Population*: *Growth* is Zero, due to the fact that it is based on *Migration* only. *Migration* is assumed Zero/Steady. So will be the *Growth* and the *Animal*: *Biomass*, in those states when the MF "*Growth on Migration only*" is active, as happens in state 12 and 20 (see Figure 2.35 Quantities and quantity value of end-states 12 and 20, and Figure 2.36 Active MFs in states where *Growth* is based on *Migration* only, "*Assume migration is zero and steady*: *Zooplankton/Fish*", and "*Population none existing*: *Fish*").

2.11.1. Dependency diagrams

These diagrams figure those state quantities and quantity values when one of the two populations growth gets Zero (defining that population extinction condition) as is based on Migration only (*Migration* is assumed Zero/Steady).

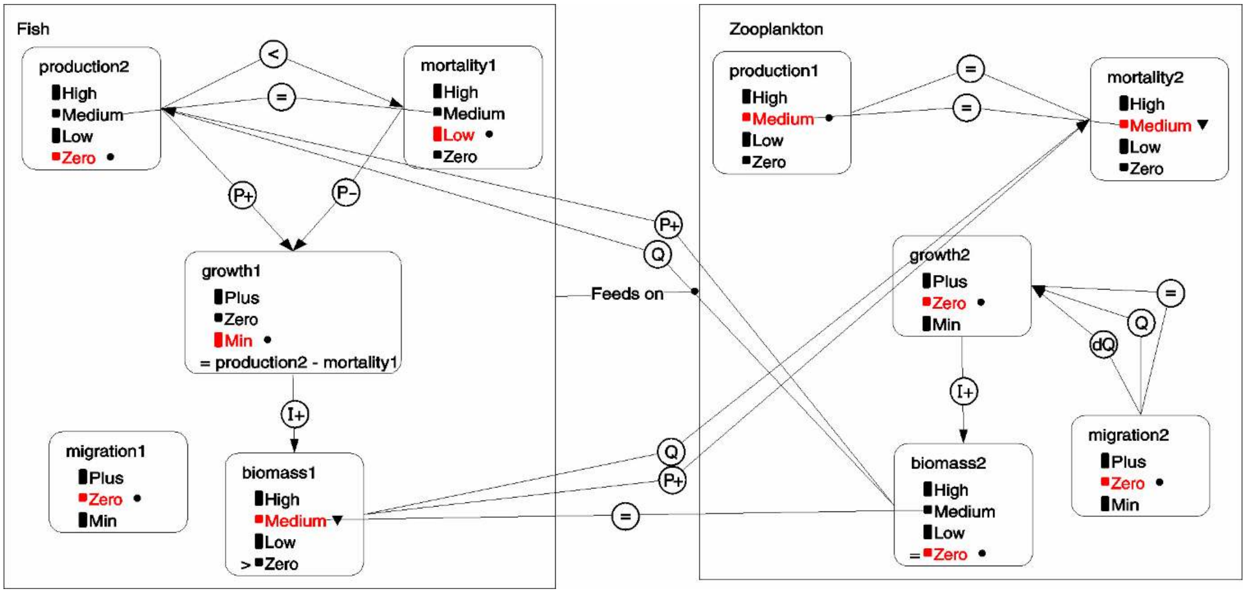


Figure 2.32 Sce07 Dependency diagram of state 9 (preceding the end-state 12):
Zooplankton growth based on *Migration* only (Migration is assumed Zero /Steady).

.

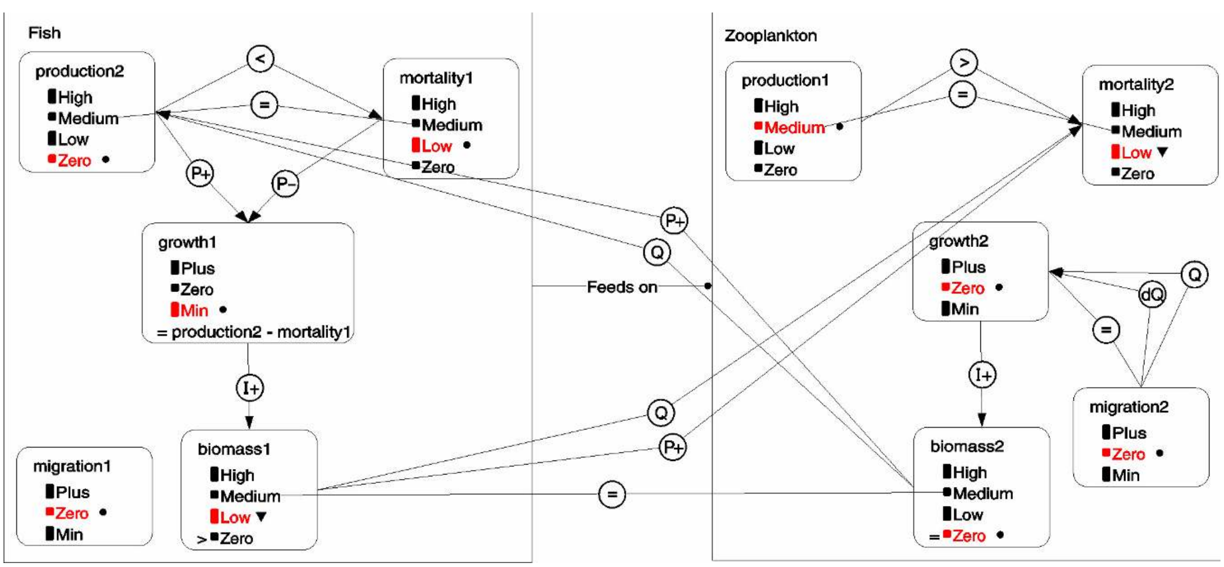


Figure 2.33 Sce07 Dependency diagram of end-state 12
(*Zooplankton: Biomass* = Zero, 0. *Zooplankton* growth based on *Migration* only (*Migration* is assumed Zero /Steady).

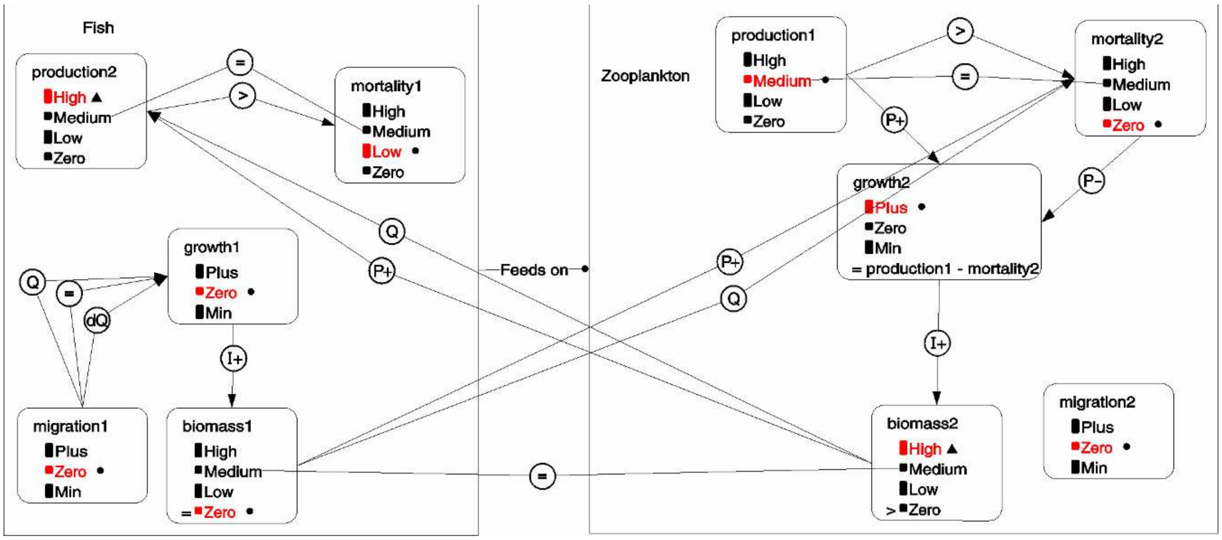


Figure 2.34 Sce07 Dependency diagram of end-state 20.
(*Fish: Biomass* = Zero, 0. *Fish* growth based on *Migration* only
(*Migration* is assumed Zero /Steady).

2.11.2. Quantities and quantity values

Quantities and quantity values of the two end-states: 12 and 20 from Sce07 state-graph are presented in Figure 2.35. In state 12, extreme quantity values that can stop the process are *Zooplankton*: *Growth*=*Biomass*=Zero. In state 20, extreme quantity values that can stop the process are *Fish*: *Growth*= *Biomass*=Zero.

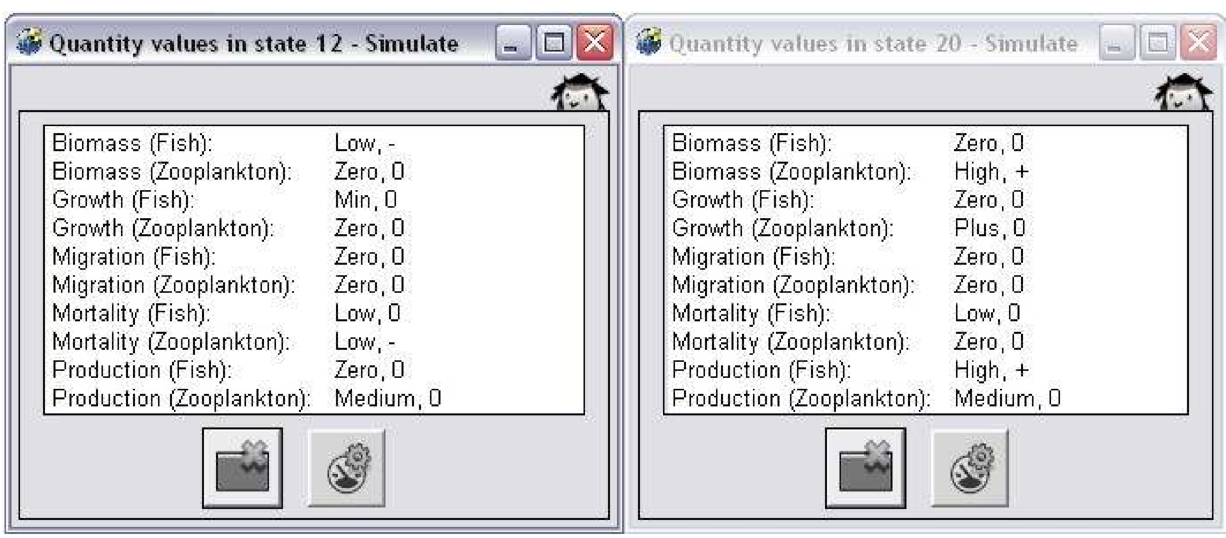


Figure 2.35 Sce07: End states 12 and 20 Quantities and Quantity values.

2.11.3. Active Model fragments

The active Model fragments in states 13, 16, 17, and 20are shown in Figure 2.36. Among these states, only in state 20 are fulfilled those conditions to stop the process.

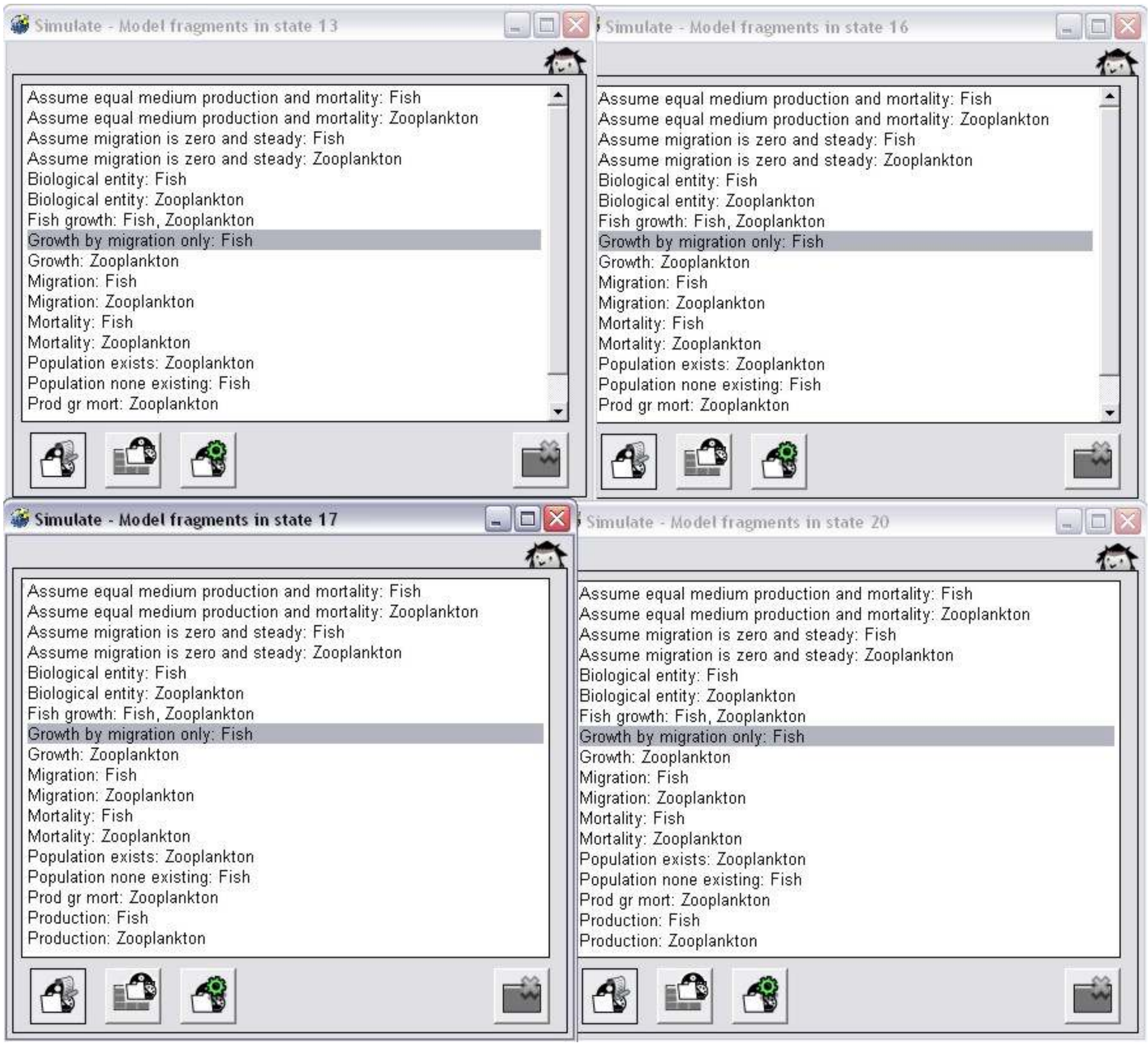


Figure 2.36 Sce07: Active Model fragments in states 13, 16, 17, and end-state 20.

2.12. Behaviour paths

In Sce07 state-graph all state-paths end with end-states 12 and 20, which results due to the particular condition for the *Animal* growth process based on *Migration* only, regardless of the *Population*: *Production* and *Mortality*, and when *Migration* is Zero/Steady. So is the *Population*: Biomass, meaning the end of the process (the *Population* extinction).

2.12.1. Relevant behaviour path

One of the most relevant behaviour paths is: [1→2→3→4→5→6→7→8→10→11→14→15], as selected in the state-graph of Sce07 (Figure 2.37).

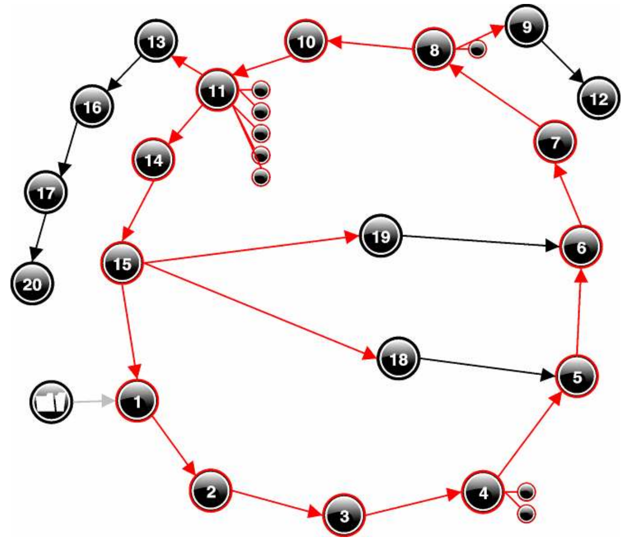


Figure 2.37 Sce07 behaviour path [1→2→3→4→5→6→7→8→10→11→14→15],

2.12.2. Equation history

Equation history shows there is a continuous process because both aquatic population Biomass is > Zero from state 1 to state 15.

Biomass (Fish) ? Zero

>	>	>	>	>	>	>	>	>	>	>	>
1	2	3	4	5	6	7	8	10	11	14	15

Biomass (Zooplankton) ? Zero

>	>	>	>	>	>	>	>	>	>	>	>
1	2	3	4	5	6	7	8	10	11	14	15

Production (Zooplankton) ? Mortality (Zooplankton)

>	>	=	<	<	<	<	<	=	>	>	>
1	2	3	4	5	6	7	8	10	11	14	15

Production (Fish) ? Mortality (Fish)

>	>	>	>	>	>	=	<	<	<	=	>
1	2	3	4	5	6	7	8	10	11	14	15

Figure 2.38 Sce07 behaviour path [1→2→3→4→5→6→7→8→10→11→14→15]: Equation history

2.12.3. Value history graphs

The two figures 2.38 and 2.39, show the behaviour of the two aquatic *Animal* populations, *Fish* and *Zooplankton*, functionally related as *Predator* and *Prey* species, respectively, in the framework of the Functional Feeding Group relationship, as follows:
Danube Delta: *Nutrient inflow* Low/Constant condition, as follows:

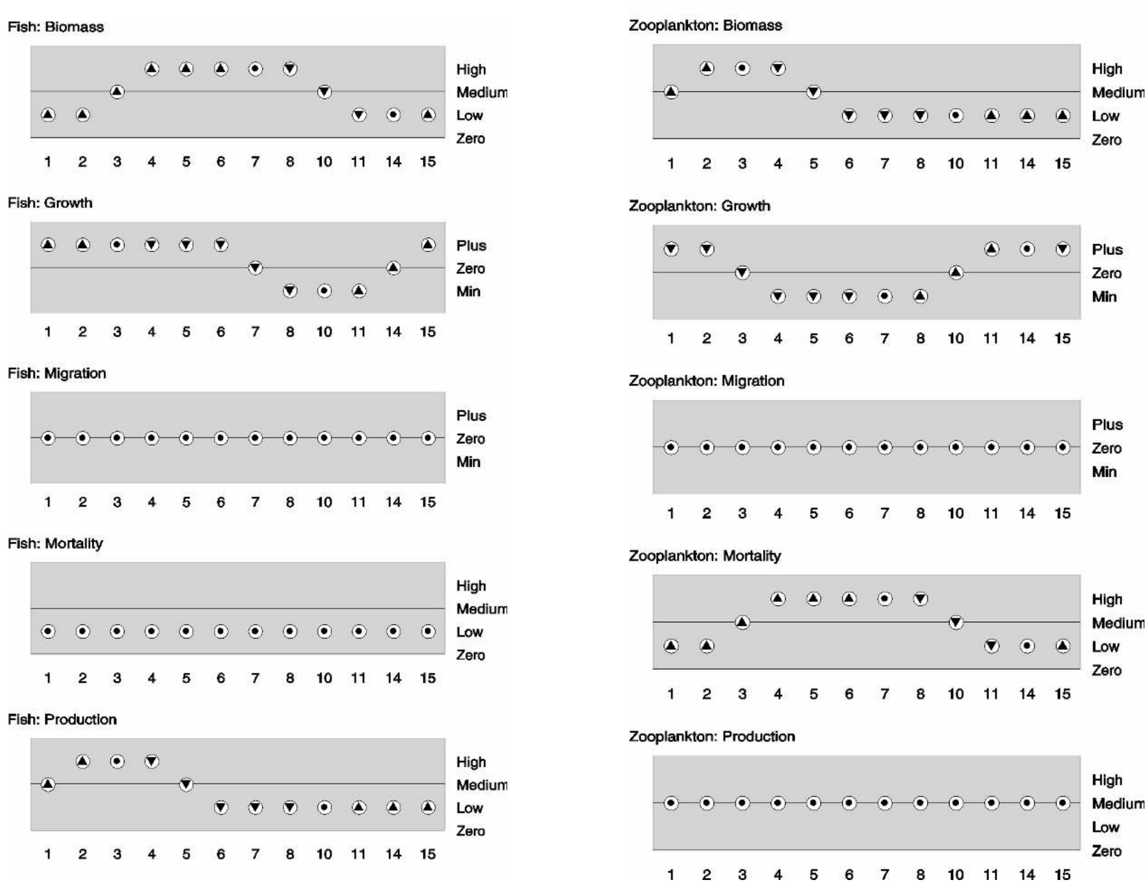


Figure 2.39 Sce07 behaviour path [1→2→3→4→5→6→7→8→10→11→14→15]:
Value history

Both Population: *Biomass* is positive, increasing and decreasing in a continuously sinusoidal change of values, which shows that there is a continuous Growth process.
In order to reduce the simulation complexity, *Migration* is assumed Zero/Steady for both Populations (meaning both of them are close populations), and *Fish*: *Mortality* and *Zooplankton*: *Production* are Low/None, and Medium/None respectively.
The only situation when one of the populations gets extinct, it's determined by the possible condition when the *Growth* of that population is based on *Migration* only, and *Migration* is assumed Zero/Steady. There are two such situations, for each of the two populations for which the two particular behaviours derive from the process close circle defined by the path of states [1→2→3→4→5→6→7→8→10→11→14→15], by two separate paths of states. One of them branches from state 8, [8→9→12], and the other one from state 11, [11→13→16→17→20], defining the extinction of *Zooplankton* (the prey species), and of *Fish* (Predator species), respectively (See Figure 2.37 Sce07 behaviour path [1→2→3→4→5→6→7→8→10→11→14→15]).

Scenarios concerning both *Plant* and *Animal* growth process State graph

2.13. Scenarios

Three Scenarios have been constructed to model both aquatic *Plant* and *Animal* population growth process, in the framework of the Functional Feeding Group relationships. These are:

Sce10 FFG nutrients diatoms and zooplankton
Sce11 FFG Diatoms Zooplankton and Fish
Sce12 FFG Zooplankton Fish and Birds

These Scenarios are constructed on the same principle, as follows:

1. Three entities are considered in any Scenario, each of them with different role within the Functional Feeding Group relationship: two of them can be predator and prey species, respectively, but the third one is both predator and prey species, in the same time;
2. The configuration is "*Feeds on*";
3. To reduce the simulation complexity, two Assumptions are introduced in Scenario construction: "*Assume migration is zero and steady*" and "*Assume medium equality for production and mortality*", and they address the three populations involved in process.

The initial situation of any aquatic *Plant* (***Diatoms*** algae species*)* and *Animal* species (***Zooplankton***, ***Fish***, ***Bird*** or ***Macroinvertebrates***) growth process, regarding the *Quantity* values (Magnitude/Derivative) of the three *Entities* (*Aquatic populations*), can be:

For the *Predator* species, the *Biomass*: Low/None, *Mortality*: Medium/Constant;
For the *Prey* species, the *Biomass*: Medium/None, the *Production*: Medium /Steady;
For the Predator/Prey: *Biomass*: Medium/None.

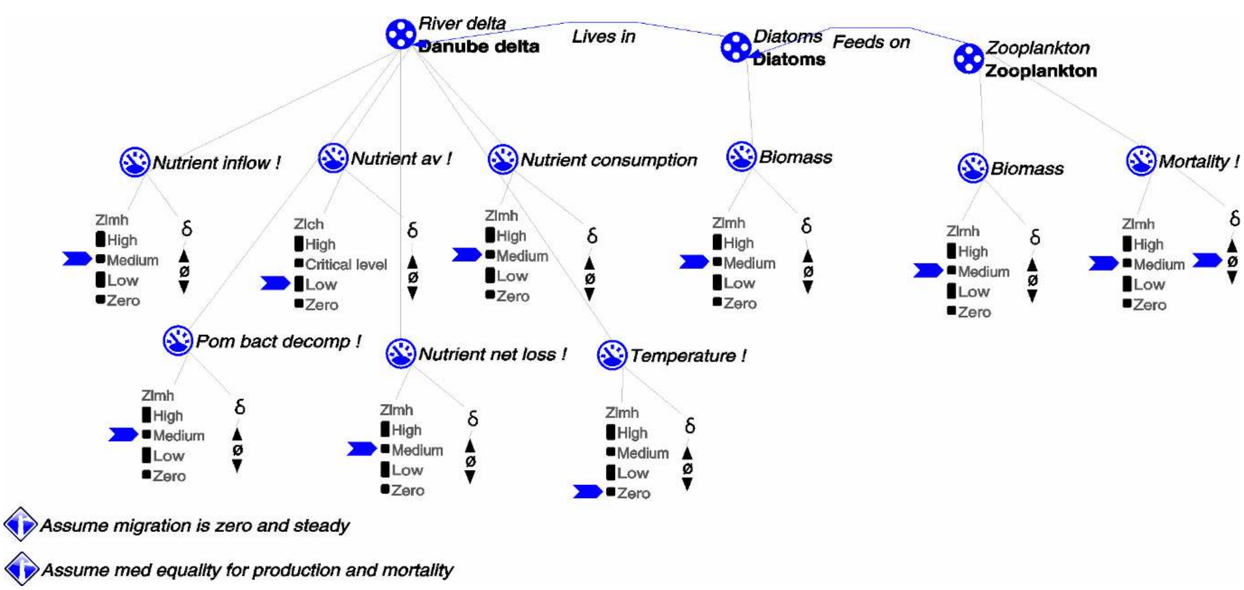


Figure 2.40.1 Sce11 FFG Diatoms Zooplankton and Fish growth process Scenario.

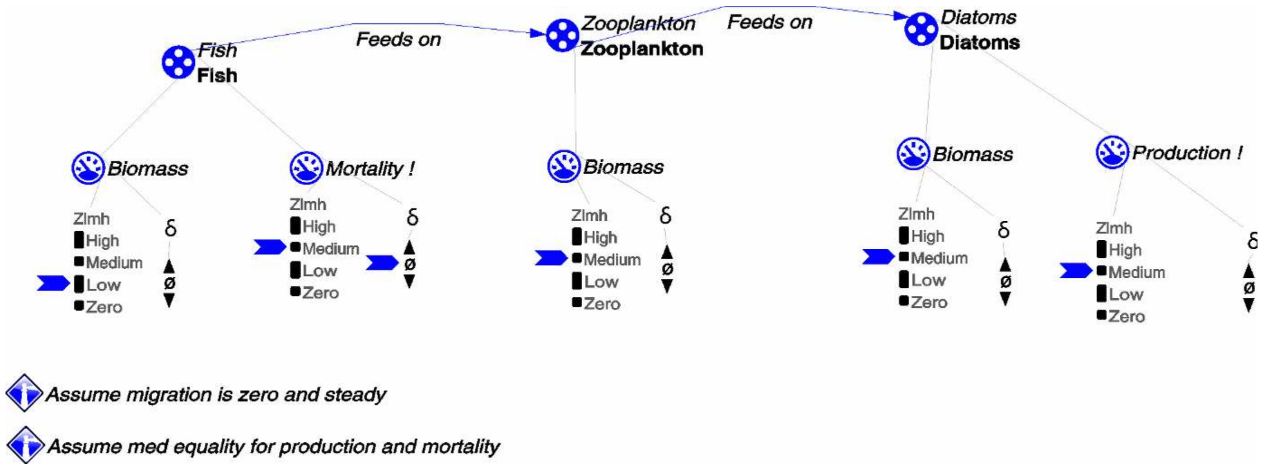


Figure 2.40.2 Sce11 FFG Diatoms Zooplankton and Fish growth process Scenario.

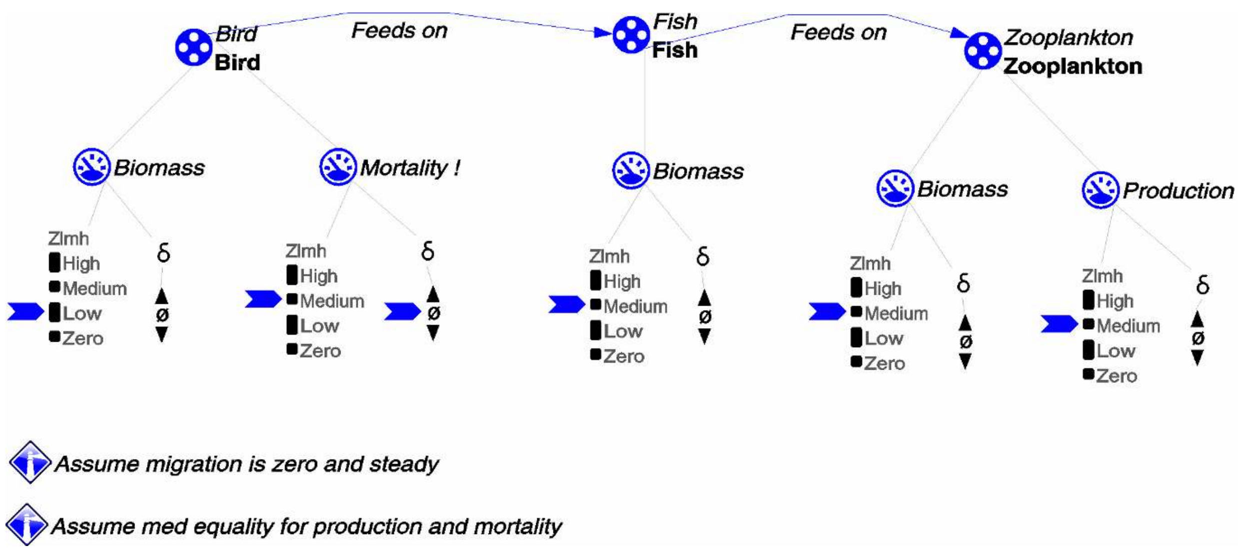


Figure 2.40.3 Sce11 FFG Diatoms Zooplankton and Fish growth process Scenario.

From the three Scenarios constructed to model the aquatic *Plant* and *Animal* population behaviour in the framework of their growth process, the simulation results are presented for one of them: Sce11 FFG *Diatoms Zooplankton* and *Fish* growth process (Figure 2.40.2 Sce11 FFG Diatoms Zooplankton and Fish growth process Scenario).

2.14. Begin states

2.14.1. Begin states definition

Within aquatic ecosystems, in the framework of any group of aquatic *Plant* and *Animal* species growth process, the main quantities that trigger this process are: *Predator*: *Production* > Zero, based on *Prey*: *Biomass*, > Zero.

A possible initial situation of this process, according to initial quantity values assigned in Scenario, (Figure 2.40) can be:

Diatoms (Prey species): Biomass, Medium/None, *Production*, Medium/Steady;
Zooplankton (Predator/prey species): *Biomass*: Medium/None, the *Production*: Medium /Steady.
Fish (Predator species): *Biomass*: Low/None, *Mortality*: Medium/Constant;

2.14.2. State-graph

From the initial situation, 1 initial state resulted (Figure 2.41).

Figure 2.41 Sce11 initial state-graph

2.14.3. Value history graph

The quantities and quantity value history of initial state is presented in Figure 2.42.

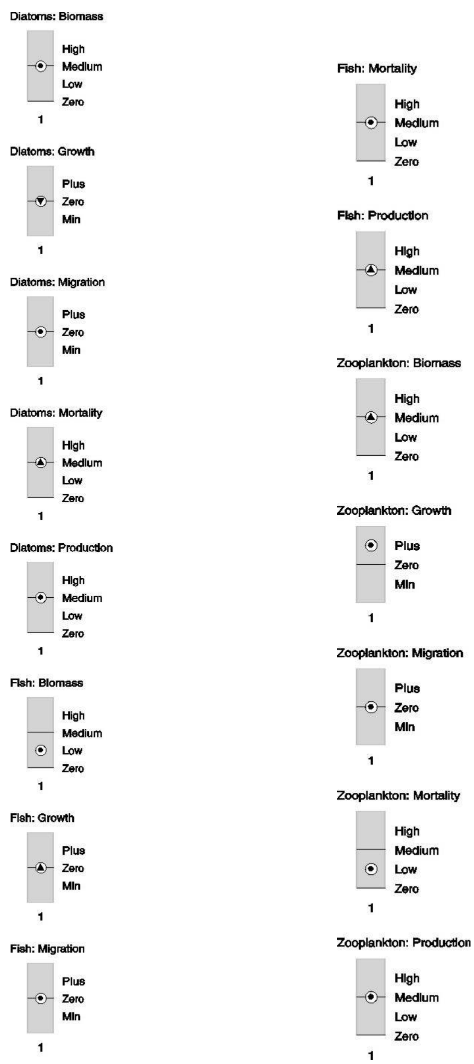


Figure 2.42 Sce11 FFG Initial state value history

It shows a possible condition for the process to start, from the three entities, quantities and quantity values (Magnitude/Derivative) point of view.

2.14.4. Equation history

Equation history of Initial state is presented in Figure 2.43.

Biomass (Diatoms) ? Zero
>
1

Biomass (Fish) ? Zero
>
1

Biomass (Zooplankton) ? Zero
>
1

Production (Diatoms) ? Mortality (Diatoms)
=
1

Production (Fish) ? Mortality (Fish)
=
1

Production (Zooplankton) ? Mortality (Zooplankton)
>
1

Figure 2.43 Sce11: Equation history of Initial state.

Initial state equation history (Figure 2. 43) shows a possible condition for the three populations to start their growth process: *Diatoms*, *Zooplankton*, and *Fish*: *Biomass*>Zero, and *Zooplankton*: *Production* > *Mortality*.

2.14.5. Dependency diagram

Dependency diagram of Initial state 1 is presented in Figure 2.44. This diagram provides information on structural and causality relationship (direct Influence I, and indirect influence, Proportionality) among three aquatic *Plant* and *Animal* populations and the growth process start possible quantity values, written in red colour (as seen in Equation history, too):

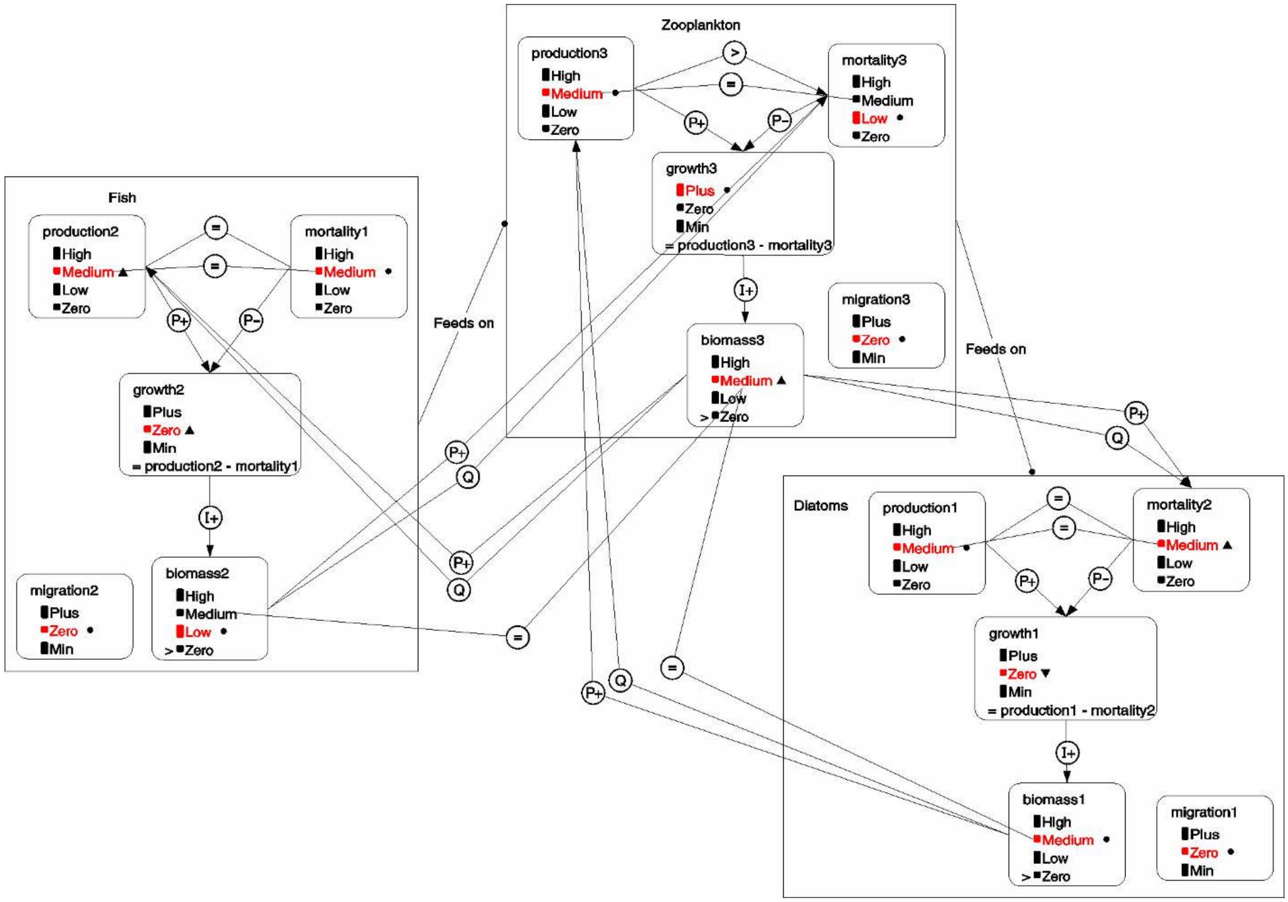


Figure 2.44 Sce11: Dependency diagram of Initial state 1.

1. *Diatoms*: *Production* =*Mortality*=Medium; *Growth* Zero, -; *Biomass* Medium, 0.
2. *Zooplankton*: *Production* > *Mortality*; *Growth* Plus, 0; *Biomass* Medium, +.
3. *Fish*: *Production* =*Mortality*=Medium; *Growth* Zero, +; *Biomass* Low, 0.
4. Note: *Migration* doesn't participate in process, for any population.

2.14.6. Active Model fragments

Active Model fragments in Initial state are as presented in Figure 2.45. Among active Model fragments, those related to the three aquatic populations (*Diatoms*, *Zooplankton*, and *Fish*) growth process are listed.

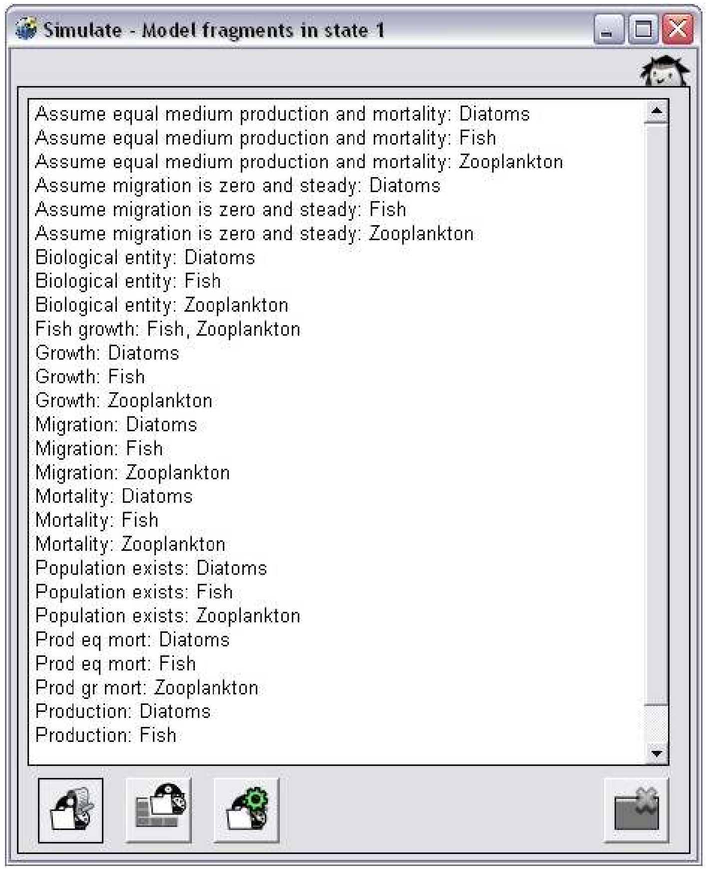


Figure 2.45 Sce11: Active Model fragments in Initial state 1.

2.15. Global State-graphs

All states generated by full simulation, starting from the only initial state 1, are presented in Figure 2.46. In this Figure the most relevant path of states is selected.
By full simulation of the initial state, a total number of 56 states are generated. Three of them are end-states: 14, 34, and 35.

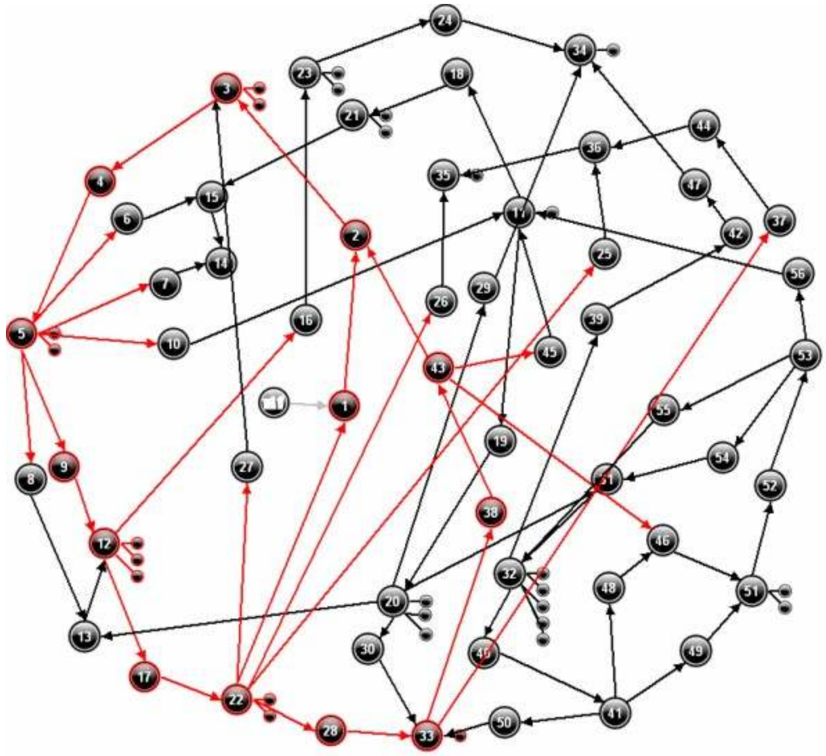


Figure 2.46 Sce11 FFG Diatoms Zooplankton and Fish growth process State-graph.
I.1 initial states: 1 (red coloured).
II. Full simulation states: 56 states.
III. 3 end states: 14, 34, and 35.

2.15.1. Value history

The global value history graphs are presented in Figure 2.47 (Annex 1 to this document).
It shows that the three population *quantities* have a continuous increase – decrease state by the values they take in a sinusoidal shape, defining a continuity of their growth process. The situations when the process stops occur when one of the populations *Biomass* becomes Zero.
The states when it occurs define that condition when the population *Growth* is based on *Migration* only (*Migration* is assumed Zero/Steady). In these states the MF "*Growth on Migration only*" is active, leading to this situation. Otherwise, the process is endless.

2.15.2. Equation history

The global value history is presented in Figure 2.48 (Annex 1 to this document). It shows the same general behaviour of the three aquatic populations as the value history, as follows:

1. The three population *Biomass* > Zero, with some situation when it gets Zero
2. The situations when one of the population *Biomass* gets Zero happen due the *Growth* is Zero, as result of one of two possible conditions:
    2.1. The population *Mortality* equals its *Production*;
    2.2. *Growth* is based on *Migration* only, and *Migration* is assumed Zero/Steady.
3. To reduce the simulation complexity, some quantities are assigned in Scenario or assumed to be Steady, such as:
    3.1. *Diatoms*/*Zooplankton*/*Fish*: *Migration* Zero/Steady;
    3.2. *Diatoms*: *Production Medium*/Steady;
    3.3. *Fish*: *Mortality* Medium/Steady.

2.16. Relevant path of states

One of the most relevant paths of states is:
[1→2→3→4→5→9→12→17→22→28→33→38→43→2], as selected (red coloured path of states) in the global state-graph (Figure 2.46 Sce11 FFG Diatoms Zooplankton and Fish growth process State-graph).

2.16.1. Value history graphs

The Value history diagram for one of the most relevant paths of states [1→2→3→4→5→9→12→17→22→28→33→38→43→2] is presented in Figure 2.49.
It's a close path of states. It defines a continuous growth process of the three aquatic populations. This population behaviour shows that it is an endless process.

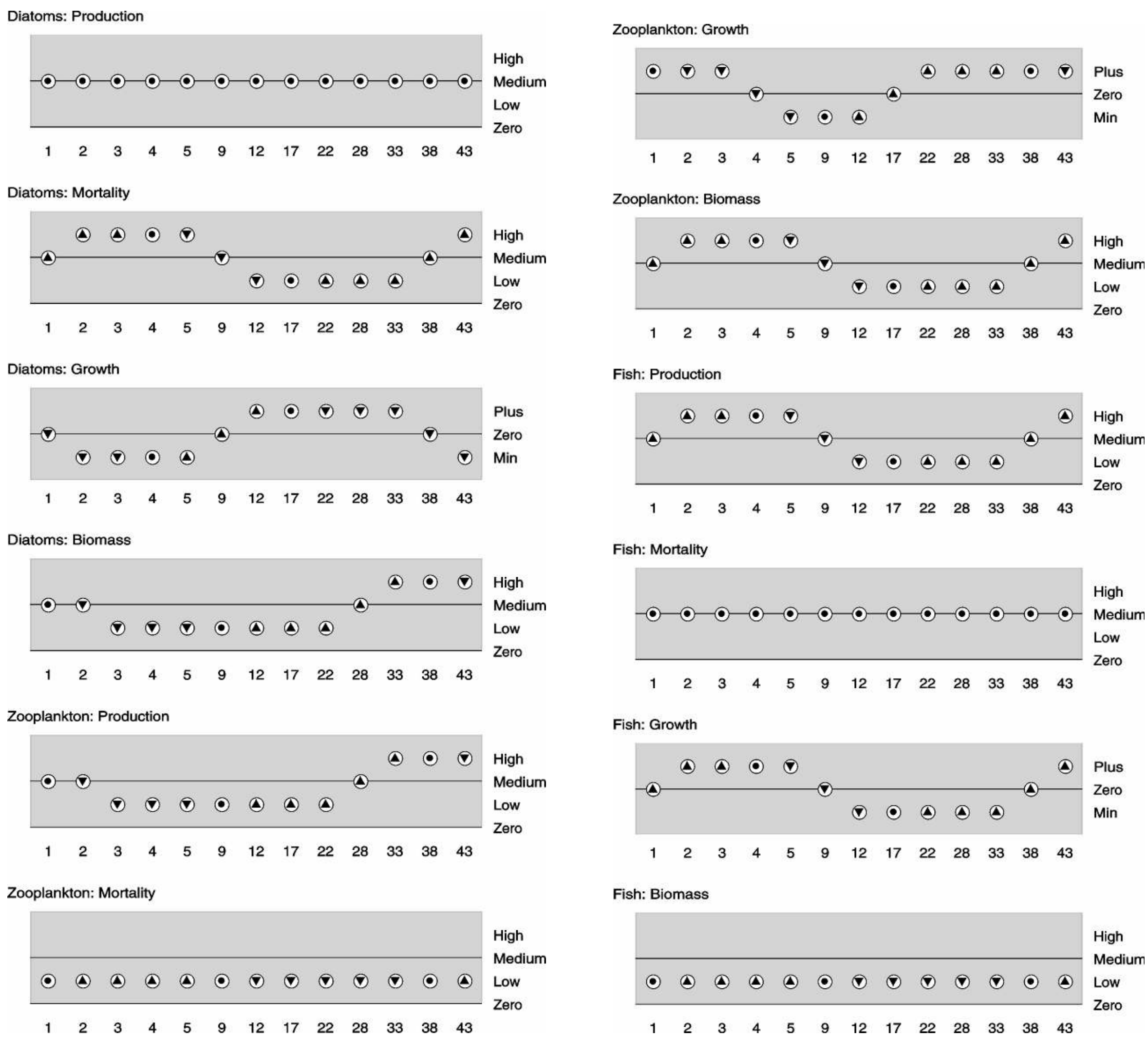


Figure 2.49 Sce11 FFG Diatoms Zooplankton and Fish growth process – Value history.

The end of the process takes place each time when one of the three populations is Zero (extinct). The only situations when one of the populations *Biomass* gets Zero happens when its *Growth* is assumed based on *Migration* only, and the *Migration* is assumed Zero/Steady. This does not happen for any of the modelled aquatic populations within the above presented path of states: [1→2→3→4→5→9→12→17→22→28→33→38→43→2].

2.17. End-states

The end-states are: 14, 34, and 35 and define the conditions when the *Growth* process stops, due to one of the three aquatic populations *Biomass* gets the value Zero, 0, meaning the population extinction condition.

2.17.1. Dependency diagrams

The Dependency diagrams (Figures 2.50, 2.51, and 2.52) of the end-states show that the population (*Diatoms*, *Zooplankton*, and *Fish*, respectively) *Growth* is Zero/Steady, so is the *Biomass*, regardless of the population Production and Mortality values, which can lead to a positive growth, but for these states, one of the active MF is "*Growth based on Migration only*", (as seen in Figure 2.53 Sce11Active MFs in end-states 14, 34, and 35.

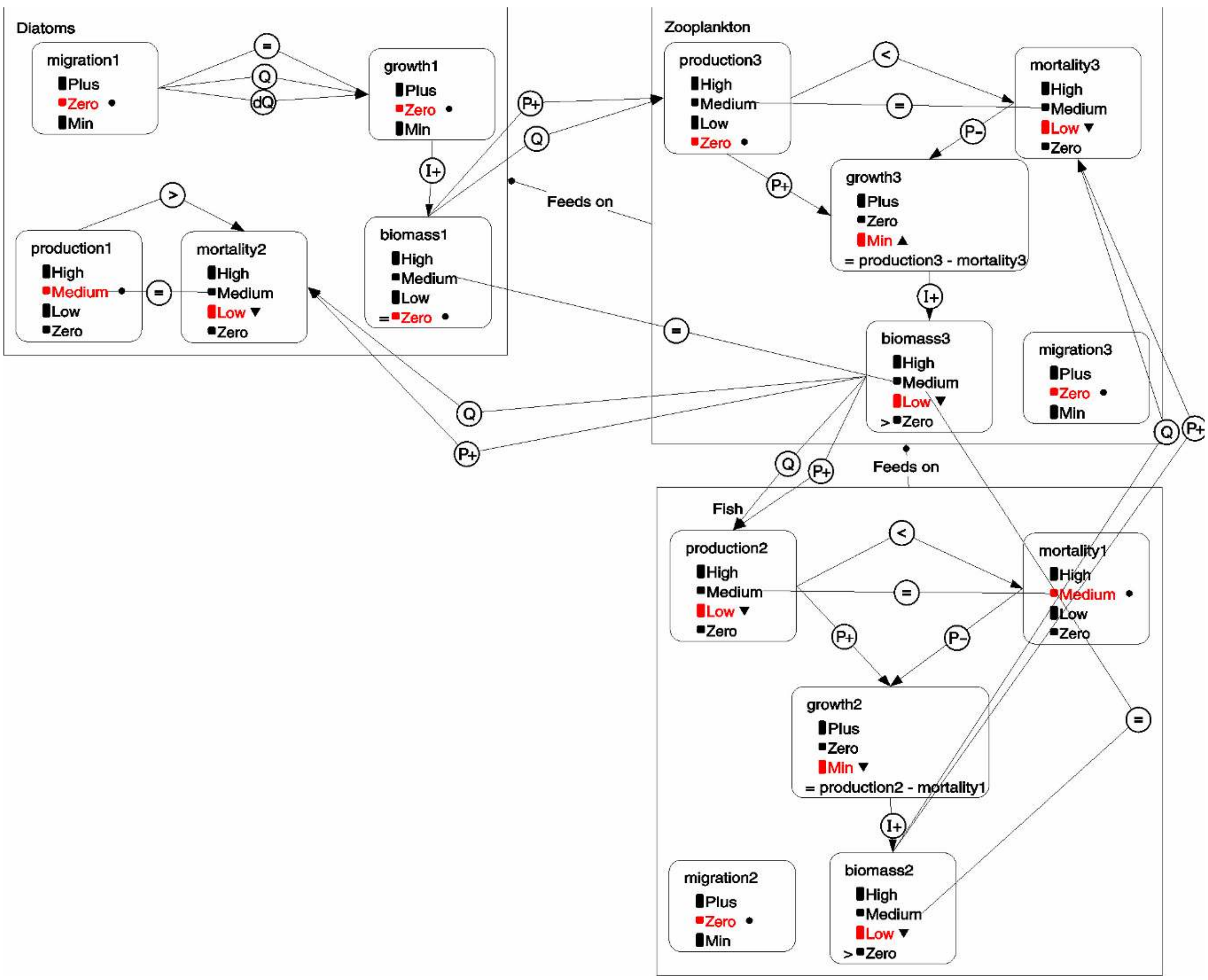


Figure 2.50 Sce11 FFG Diatoms Zooplankton and Fish growth process Dependency diagram of end-state 12: *Diatoms* growth is based on *Migration* only (*Migration* is Zero /Steady).

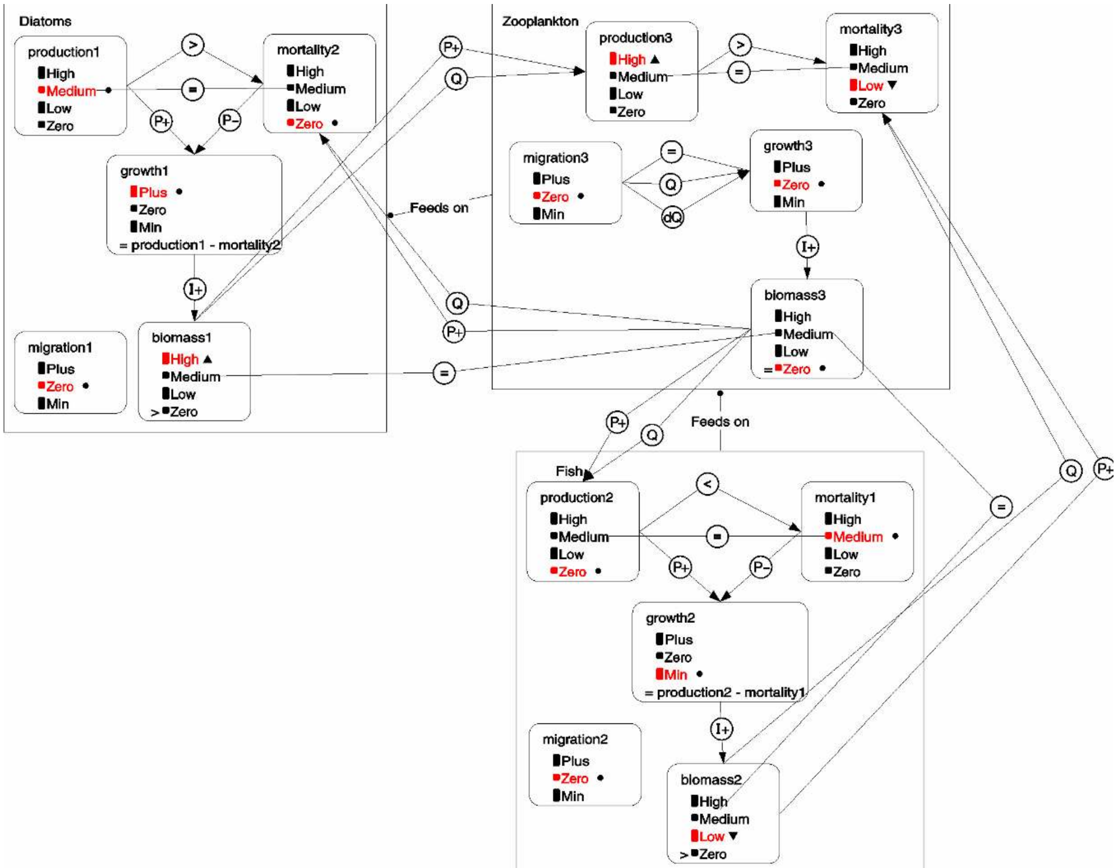


Figure 2.51 Sce11 FFG Diatoms Zooplankton and Fish growth process Dependency diagram of end-state 34: *Zooplankton* growth is based on *Migration* only (*Migration* is Zero /Steady).

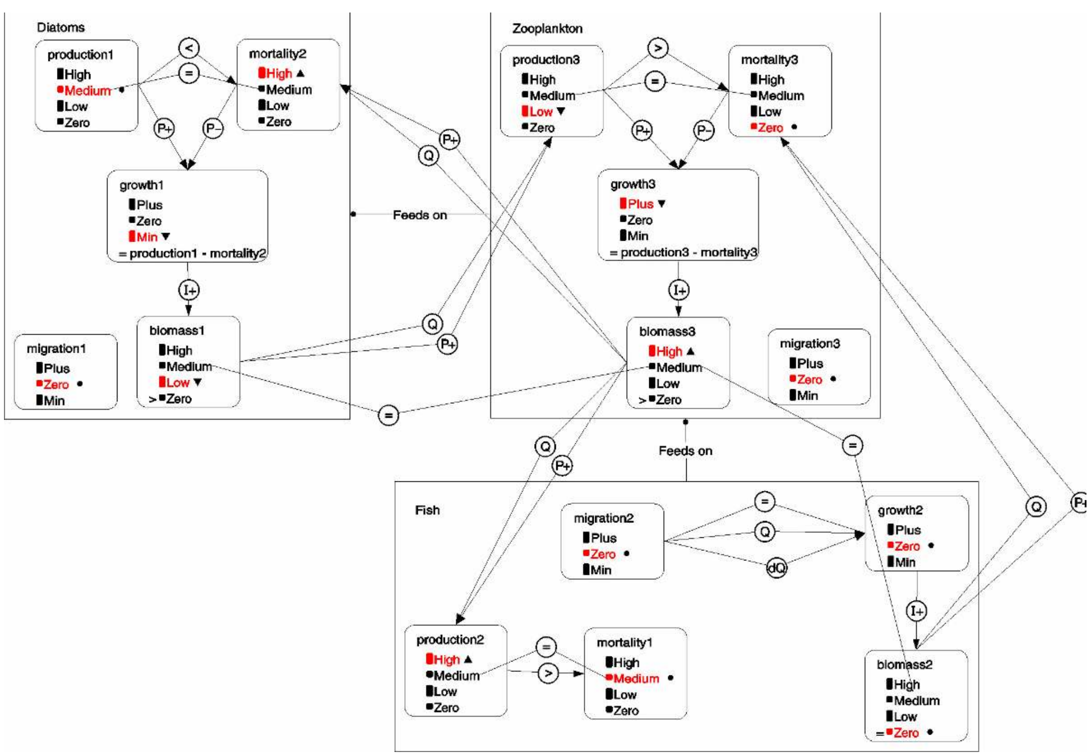


Figure 2.52 Sce11 FFG Diatoms Zooplankton and Fish growth process Dependency diagram of end-state 35: *Fish* growth is based on *Migration* only (*Migration* is Zero /Steady).

2.17.2. Active Model fragments

The active MFs in end-states are the same with those in initial states, excepting the one MF "*Growth by migration only*" (where Migration is assumed Zero/Steady) as shown in Figure 2.53.

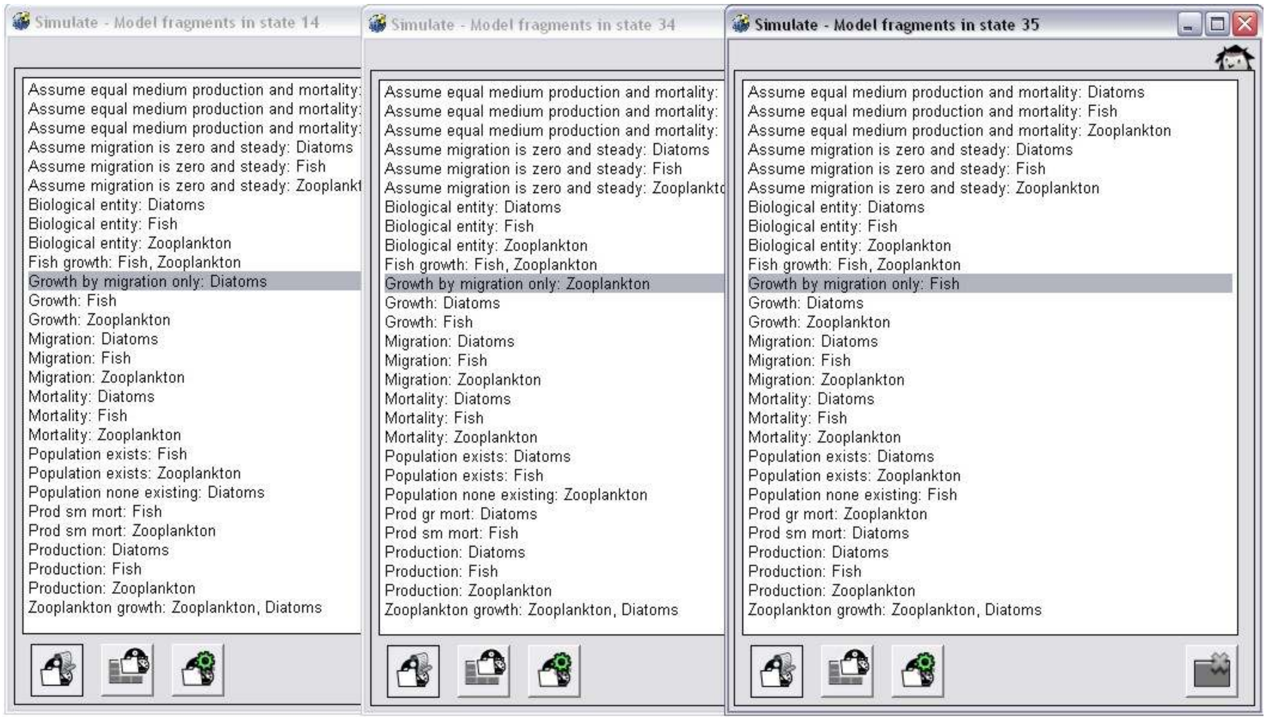


Figure 2.53 Sce11 FFG Diatoms Zooplankton and Fish growth process.
Active MFs in end-states 14, 34, and 35

2.18. Relevant behaviour paths of states

2.18.1. Value history graphs

A typical behaviour for a population to gets the value Zero for its *Biomass* quantity is shown in Figure 2.54 Sce11 FFG Diatoms Zooplankton and Fish growth process – path of states [1→2→3→4→5→6→15→14] which ends with the end-state 14.

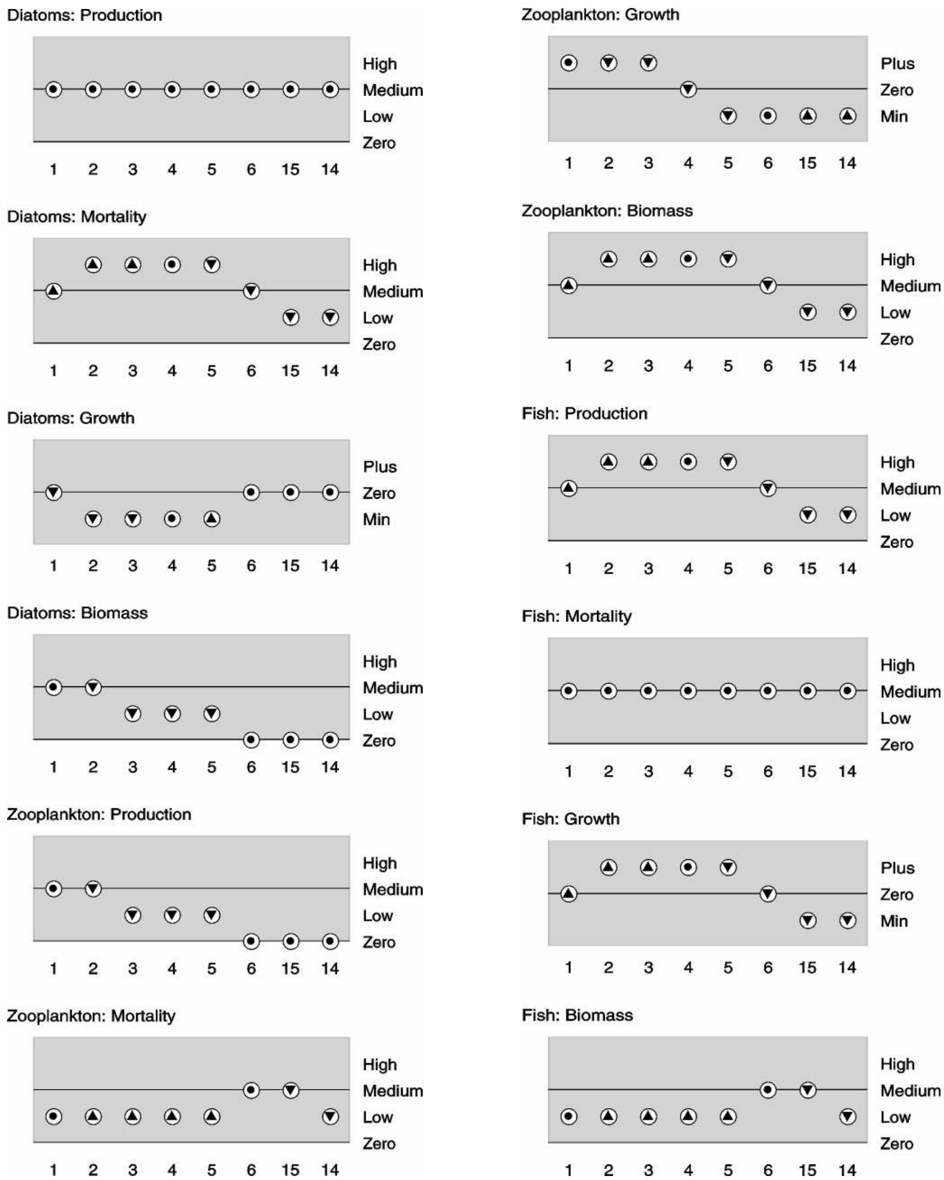


Figure 2.54 Sce11 FFG Diatoms Zooplankton and Fish growth process – path of states [1→2→3→4→5→6→15→14] value history.

This graph shows that among the three populations, the only becoming Zero is the *Diatoms* population, because its *Growth* is Zero, 0 for the last three states: 6, 15, and 14, because in all these states the *Growth* is based on *Migration* only, regardless of the *Diatoms*: *Production* and *Mortality* values. The process stops only in the end-state 14.
One can conclude that if the condition "*Growth on migration only*", when *Migration* is assumed Zero/Steady, wouldn't exist, the process never stops.

Scenarios concerning the *Water pollution* process State graph

2.19. Scenarios

Three Scenarios have been constructed to model the Danube Delta Biosphere Reserve water pollution process, its negative effects and the ways it propagates to aquatic biotic component (Aquatic biological entities: Flora and Fauna populations) living in the aquatic ecosystems of the modelled system. These are:

Sce13 DD (Danube Delta) Water pollution process
Sce14 DD Water pollution and DD aquatic population biodiversity
Sce15 DD Water pollution and Black Sea biodiversity
These Scenarios are constructed keeping the same principles:

4. The modelled system's external influences (*Agents*) participating in this process are:
   4.1 *Agriculture*: *Nutrient run-off* which participates in the water pollution process only if in high content. For values equal or smaller than Medium it participates in *Plant* growth process, as main food resource for any *Plant* species;
   4.2 *Industry*: *Heavy metals*, which have the property of bioaccumulation in any aquatic biological entity, leading to that entity pollution, even *Mortality* if in Medium/High concentration in water.
5. The third water pollution component is given, mainly by Cyanotoxins. They are produced in water if there is a content of some poisoning species of *Blue-green algae* (Cyanobacteria), which contain Cyanotoxins in their cells.
6. To reduce the simulation complexity, Assumptions are introduced in Scenario construction:
   6.1 "*Assume nutrient consumption is zero and steady*" (in Sce13);
   6.2 "*Assume nutrient consumption is zero and steady*", "*Assume Migration is zero and steady*"; and "*Assume Production is medium and steady*" (in Sce14);
   6.3 "*Assume nutrient consumption is zero and steady*", "*Assume Migration is zero and steady*" (in Sce15).

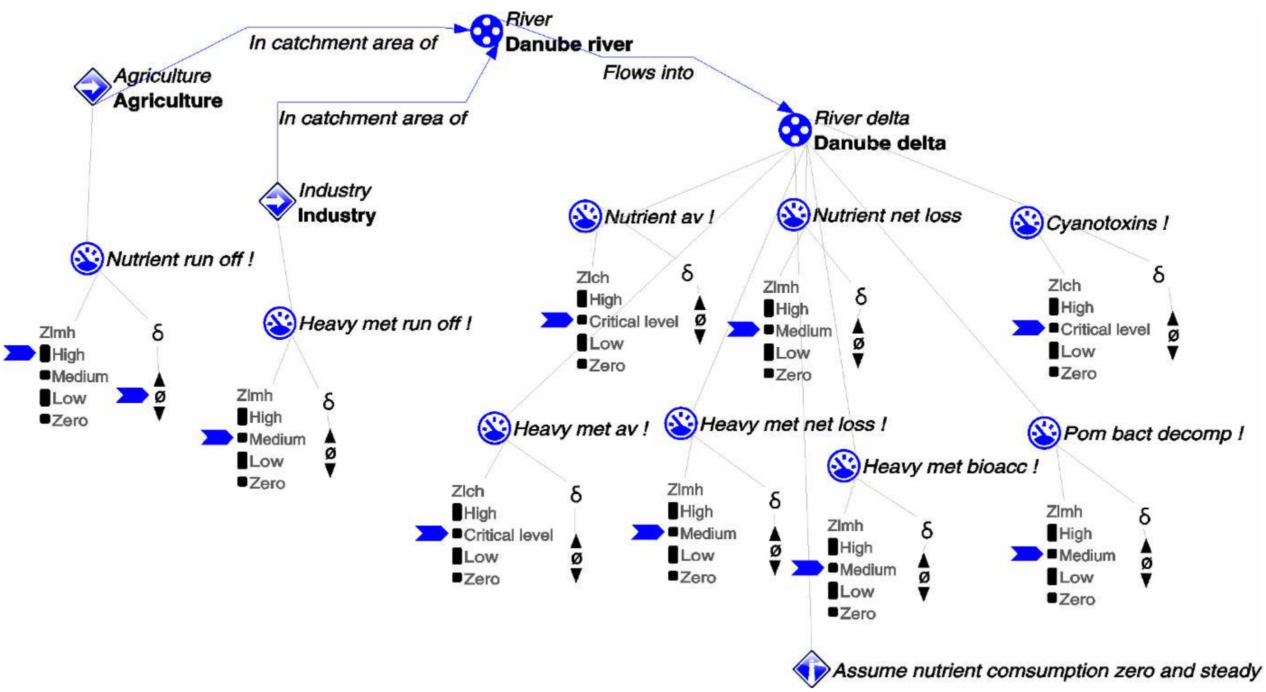


Figure 2.55 Sce13 DD Water pollution process Scenario.

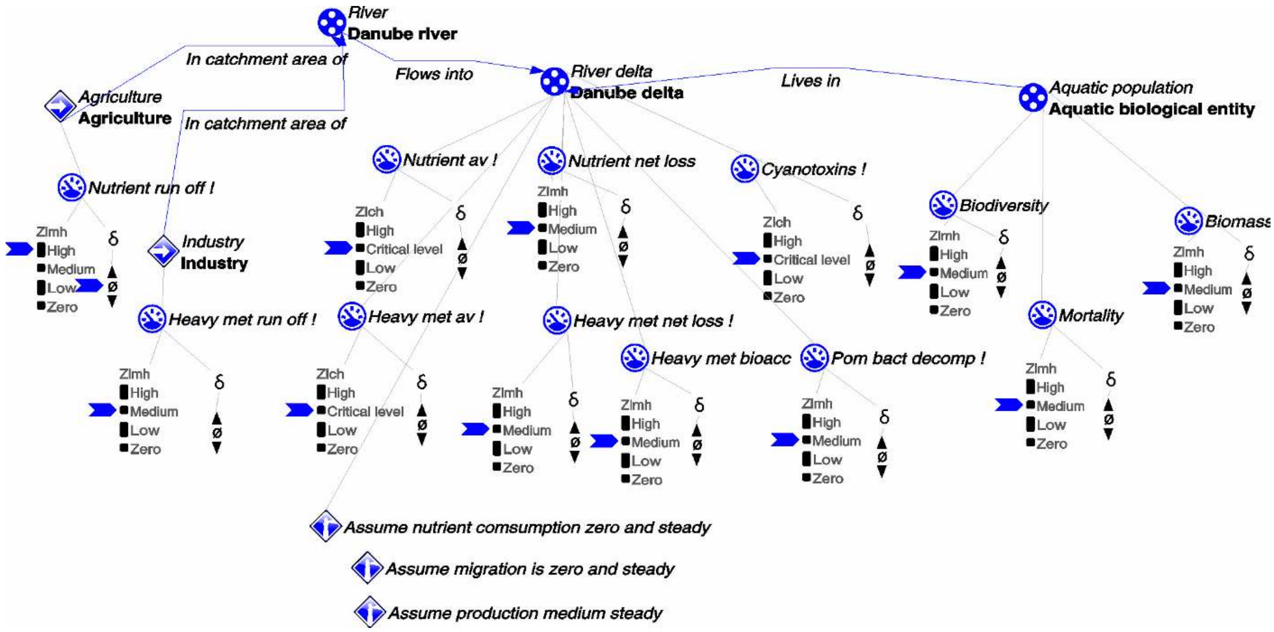


Figure 2.56 Sce14 DD Water pollution and DD aquatic population biodiversity Scenario.

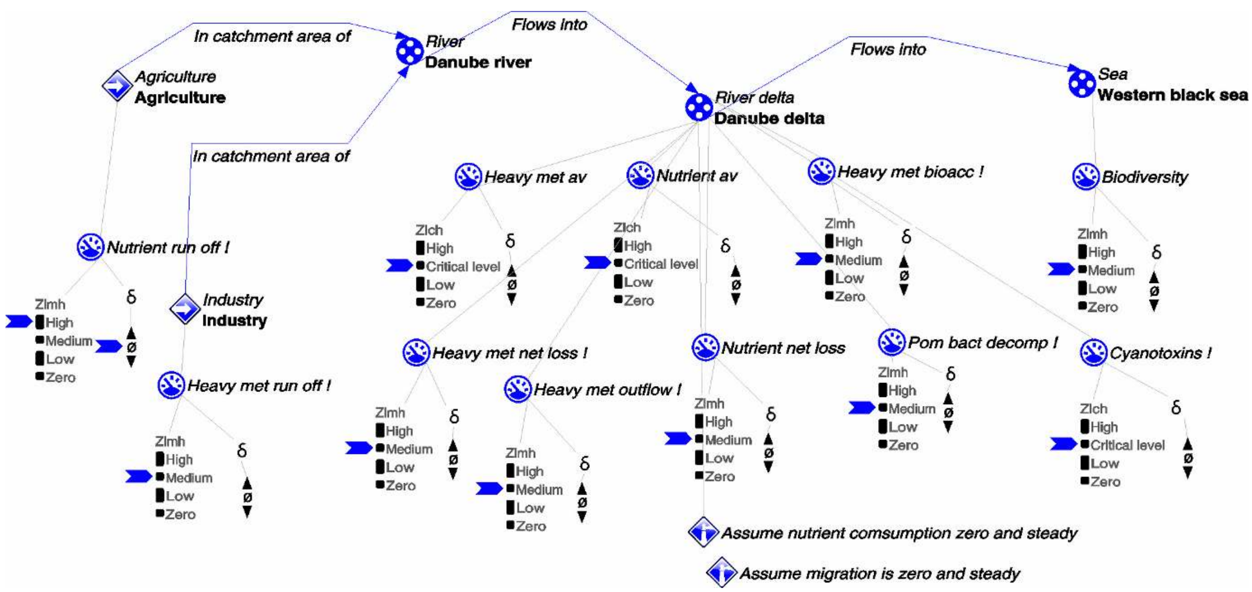


Figure 2.57 Sce15 DD Water pollution and Black Sea biodiversity Scenario.

From the three Scenarios constructed to model the Water pollution process, the simulation results are presented for one of them: Sce14 DD Water pollution and DD aquatic population biodiversity Scenario (Figure 2.56).

2.20. Begin states

2.20.1. Begin state definition

Begin states of the process define the system possible initial condition that triggers the process, meaning changes in the system quantity values as result of the active process. Begin states result from the initial quantity values as they are assigned in Scenario (Figure 2.57 Sce15 DD Water pollution and Black Sea biodiversity Scenario), as follows:

1. *Agriculture*: *Nutrient run-off* High/Constant/None;
2. *Industry: Heavy metals run-off* Medium/Increase;
3. *River Delta*: *Nutrient available* Critical value/Increase;
4. *River Delta*: *Nutrient net loss* Medium/None;
5. *River Delta*: *Heavy metals available* Critical value/Increase;
6. *River Delta*: *Heavy metals net loss* Medium/ Increase;
7. *River Delta*: *Heavy metals bioaccumulation* Medium/ None;
8. *River Delta*: *Cyanotoxins* Critical value/Increase;
9. *River Delta*: *Pom (Particulate Organic matter) bacterial decomposition* Medium/ Increase;
10. *Aquatic population*: *Biomass* Medium/ None;
11. *Aquatic population*: *Biodiversity* Medium/ None;
12. *Aquatic population*: *Mortality* Medium/ None;

2.20.2. State-graph

From the initial situation, 3 initial states result as shown in Figure 2.58.

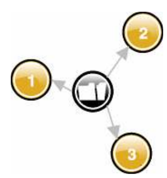


Figure 2.58 Sce14 initial state graph.

2.20.3. Equation history

The three initial state equation history (Figure 2.59) shows that a possible start of the process can occur when:

1. *Danube Delta*: *Heavy metals inflow* > *Heavy metals net loss*;
2. *Danube Delta*: *Nutrient inflow* > *Nutrient net loss*;
3. *Aquatic biological entity*: *Biomass* is > Zero;
4. *Aquatic biological entity*: *Mortality* equals *Production*.

Biomass (Aquatic biological entity) ? Zero

> > >

1 2 3

Heavy met inflow (Danube delta) ? Heavy met net loss (Danube delta)

> > >

1 2 3

Nutrient inflow (Danube delta) ? Nutrient net loss (Danube delta)

> > >

1 2 3

Production (Aquatic biological entity) ? Mortality (Aquatic biological entity)

= = =

1 2 3

Figure 2.59 Sce14: Equation history of Initial state.

2.20.4. Value history graphs

The quantities and quantity value history of initial states is presented in Figure 2.60.
A common behaviour of the system’s components, both those involved in water pollution process and biological component (any *Aquatic biological entity*), from their quantity values point of view is that all keep the same value (the same Magnitude and Derivative) within all initial states, as they are assigned in Scenario, excepting two of them, and these are:

1. *Danube Delta*: *Nutrient net loss* has three different initial values induced by the three derivatives: Decrease, Stable, and Increase, meaning Medium, - ; Medium, 0; and Medium, +. This happens because this is the only state variable which quantity results as Nutrient lost in the system, after a part from *Danube Delta*: *Nutrient inflow* is consumed as *Danube Delta*: *Nutrient consumption* and another part is added as result of *Danube Delta*: *POM bacterial decomposition* process. All of them have the same value in the three initial states. Also, the *Nutrient net loss* value in Scenario is Medium/None. This way, there is assigned a precise information about Magnitude (Medium), but no one about Derivative (None) and the machine engine constructed all possible conditions from the Derivative point of view, meaning: Medium, -; Medium, 0; and Medium,+.
2. *Danube Delta*: *Nutrient build-up rate* has three different initial values as this quantity depends closely on the *Nutrient net loss.* These values are Plus, +; Plus, 0; and Plus, -.

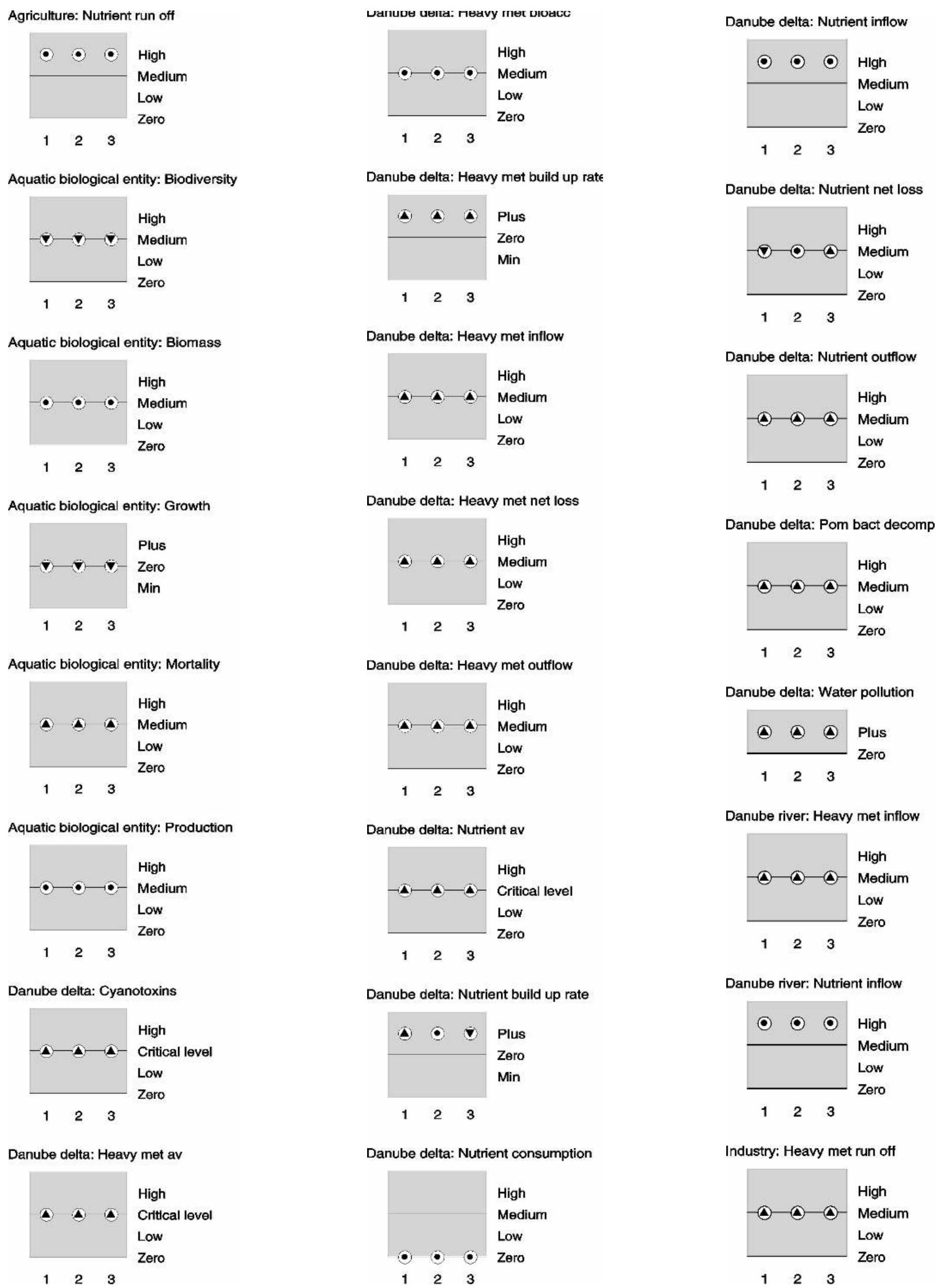


Figure 2.60 Sce14 Initial state's value history.

2.20.5. Quantities and quantity values

Figure 2.61 provides information on the system's components (*Entities*) involved in water pollution process and their quantities and quantity values as provided by the Value history diagrams (Figure 2.60), and described

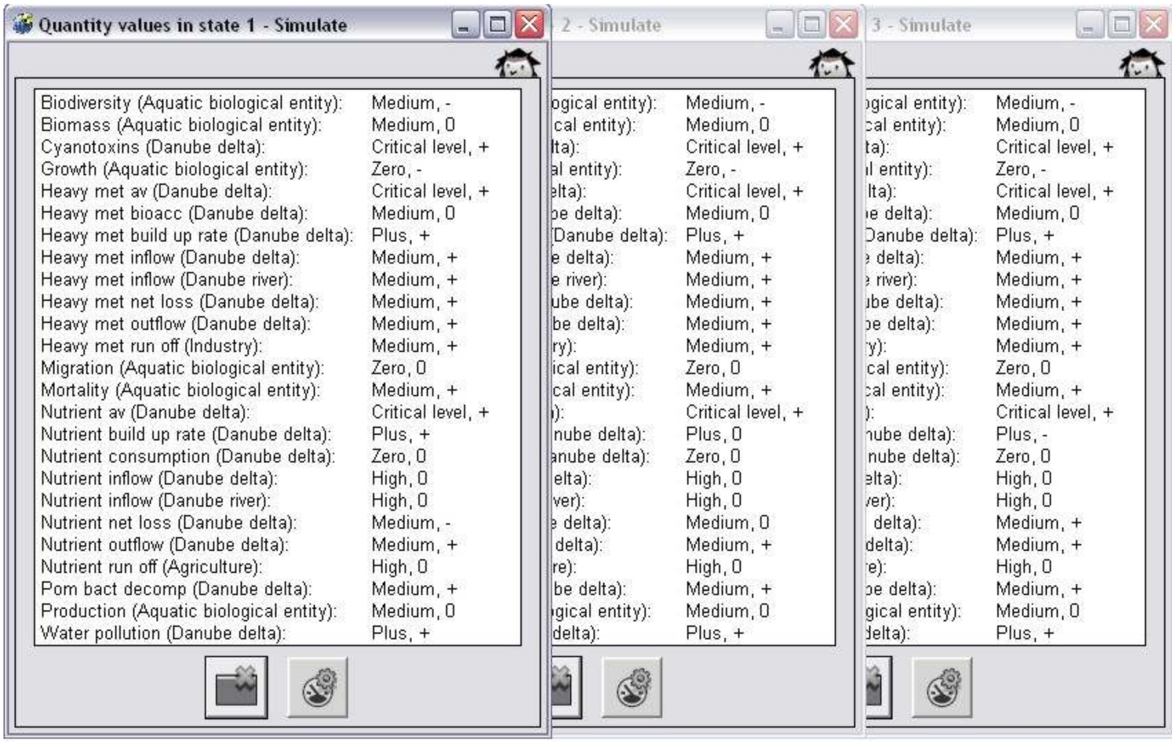


Figure 2.61 Sce14 The three initial states Entities, Quantities, and quantity values

within the above subsection. The *Danube Delta*: *Water pollution* has the value Plus, +, indicating that the process is active.

2.20.6. Dependency diagram

The diagram presented in Figure 2.62 provides information on structural and causality (Influence I, or Proportionality P), correspondence (Q, dQ) and in/equality (=, >, <) dependency relationships among the system's water pollutants (*Nutrients*, *Heavy metals* and *Cyanotoxins*), any *Aquatic biological entity*, involved in Water pollution process and its effect on Aquatic populations, as follows:

5. *Danube River: Nutrient inflow* and *Heavy Metals inflow* main resources are the two system's external influences (*Agents*): *Agriculture*: *Nutrient run-off* and *Industry*: *Heavy metals run -off,* respectively, localised "*In catchment area of*" the River. There is a close relationship (P+, Q) between *Nutrient run-off* from Agriculture lands and *Nutrient* that enters the *Danube River*. The same relationship occurs between *Heavy metals run-off* from *Industrial* zones and *Heavy metals* that enter the *Danube River*. From the *River*, these two main water pollutants reach the *Danube Delta* aquatic ecosystems.
6. A part of *Danube Delta*: *Nutrient inflow* stays in the system and contributes to *Nutrient available for Plant* species growth while another part is lost (*Nutrient net loss*), either through *Nutrient outflow* or *Nutrient consumption* (by aquatic *Plant* species only).
7. So happens with *Danube Delta*: *Heavy metals inflow*. The only difference is that a part of the *Heavy metals inflow* is lost (*Heavy metals net loss*) as they are bioaccumulated within any *Aquatic biological entity* body both of *Plant* and *Animal* species.

8. A part of *Nutrient net loss* and *Heavy metals net loss* is recycled from dead organic matter as result of Particulate Organic matter bacterial decomposition (*Pom bact decomp*) process.
9. *Danube delta*: *Water pollution rate* is the result of three main water pollutants: *Danube delta*: *Nutrient available*, *Heavy metals available* and *Cyanotoxins;*

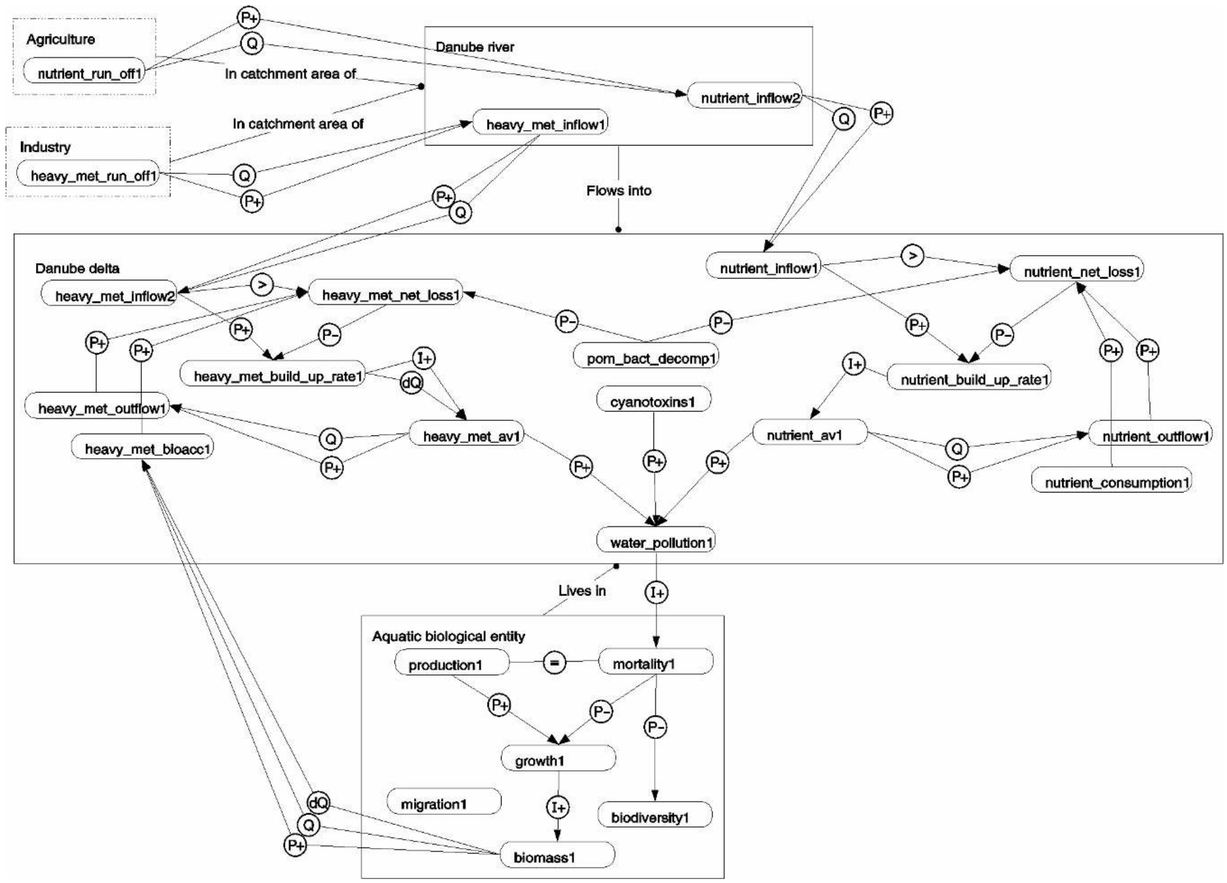


Figure 2.62 Sce14: Dependency (causal model) diagram of Initial state 1.

10. *Danube delta*: *Water pollution rate* has a direct positive influence (I+) on any *Aquatic biological entity*: *Mortality*. That signifies that a positive rate of Water pollution process induces an increase of *Mortality* for any Aquatic population.
11. *Aquatic biological entity*: *Mortality* has an indirect negative influence (P-) on any *Aquatic biological entity*: *Biomass*.

2.20.7. Active Model fragments

The MFs active in initial states are presented in Figure 2.63.

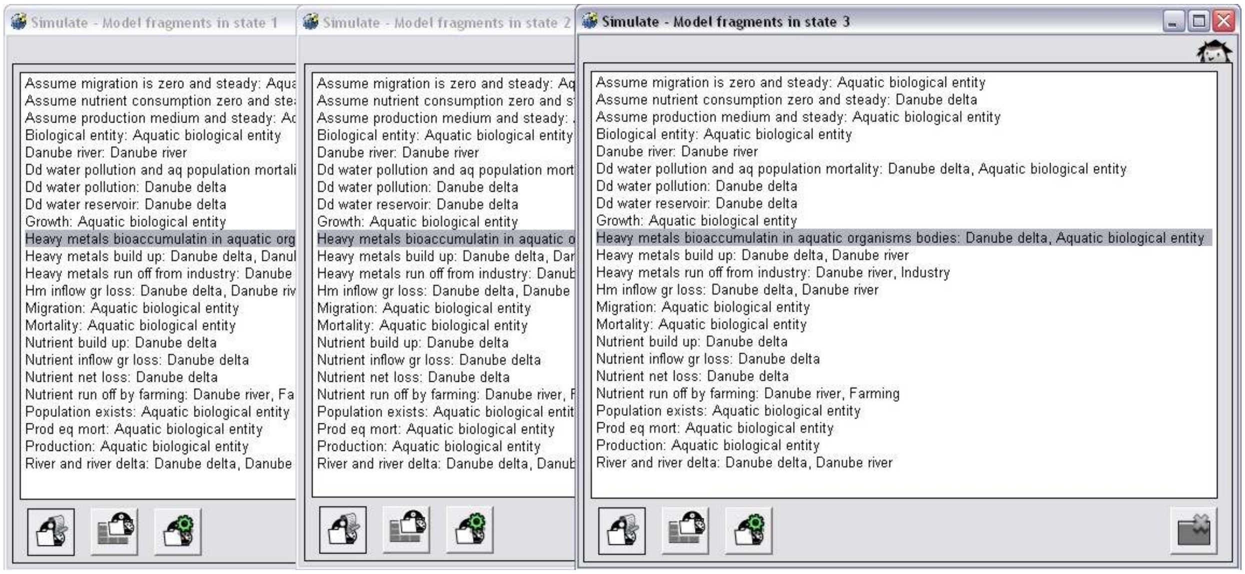


Figure 2.63 Sce14: Active Model fragments in Initial states 1, 2, and 3.

The above Figure (2.63) provides information on Model fragments used in the simulation process. As the figure shows, the same MFs are used in all initial states (1, 2, and 3).

2.21. Global State-graphs

All states generated by full simulation, starting from the three initial states 1, 2, and 3 are presented in Figure 2. 64. By full simulation of the initial states, a total number of 20 states are generated. Five of them are end-states: 12, 14, 15, 17, and 20.

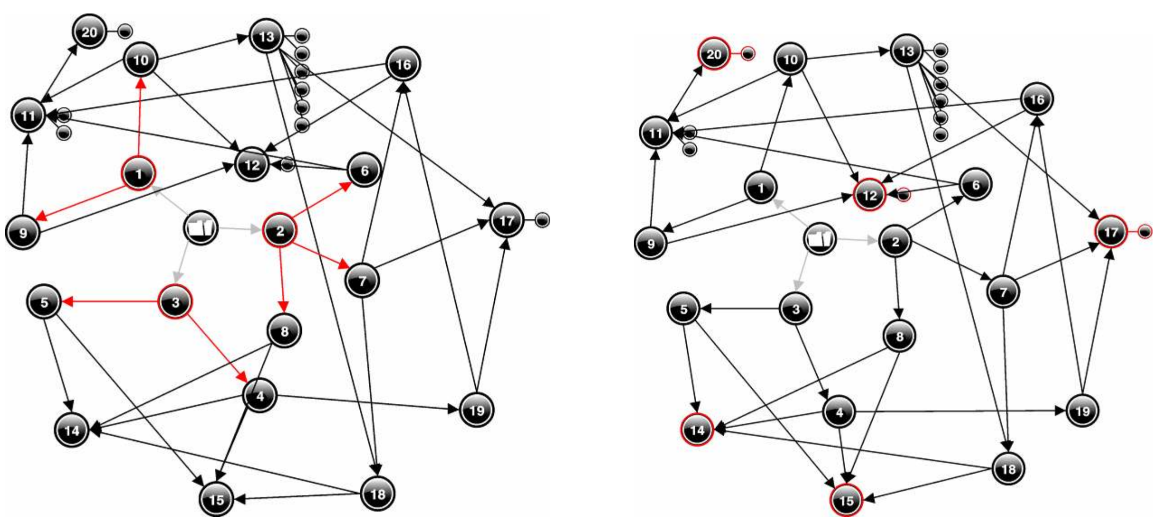


Figure 2.64 Sce14 DD Water pollution and DD aquatic population biodiversity global State-graph

I. 3 initial states: 1, 2, and 3 (LHS, red coloured).
II. Full simulation states: 20 states.
III. 5 end states: 12, 14, 15, 17, and 20 (RHS, red coloured).

2.21.1. Equation history

The global value history is presented in Figure 2.65. It shows the same general behaviour of the system components involved in Water pollution process and its negative effect on any *Aquatic biological entity*, as shown by the three initial states (Figure 2.59 Sce14: Equation history of Initial state).
The only difference: *Aquatic biological entity*: *Production* is smaller (<) than *Mortality* for all produced states starting from initial states 1, 2, and 3 (4 ÷ 20). This is the result of active *Water pollution* process that has a positive direct influence (I+) on *Aquatic biological entity*: *Mortality*.

Biomass (Aquatic biological entity) ? Zero

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>

Heavy met inflow (Danube delta) ? Heavy met net loss (Danube delta)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>

Nutrient inflow (Danube delta) ? Nutrient net loss (Danube delta)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>	>

Production (Aquatic biological entity) ? Mortality (Aquatic biological entity)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
=	=	=	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<	<

Figure 2.65 Sce14 DD Water pollution and DD aquatic population biodiversity
State-graph equation history

2.21.2. Value history graphs

The global state- graph value history is presented in Figures 2.66 (I), 2.66 (II), and 2.66 (III).

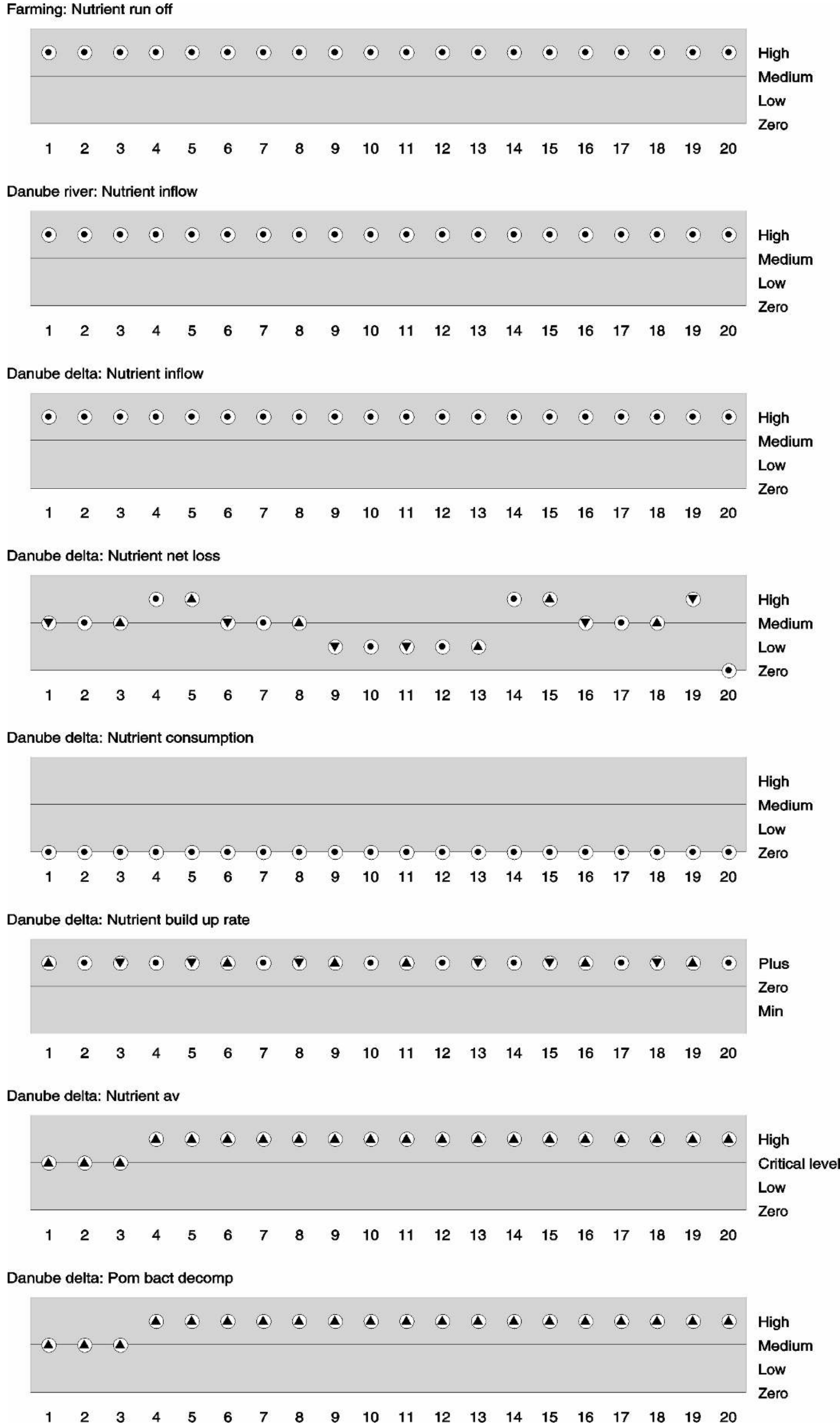


Figure 2.66 (I) Sce14 DD Water pollution and DD aquatic population biodiversity: State-graph value history

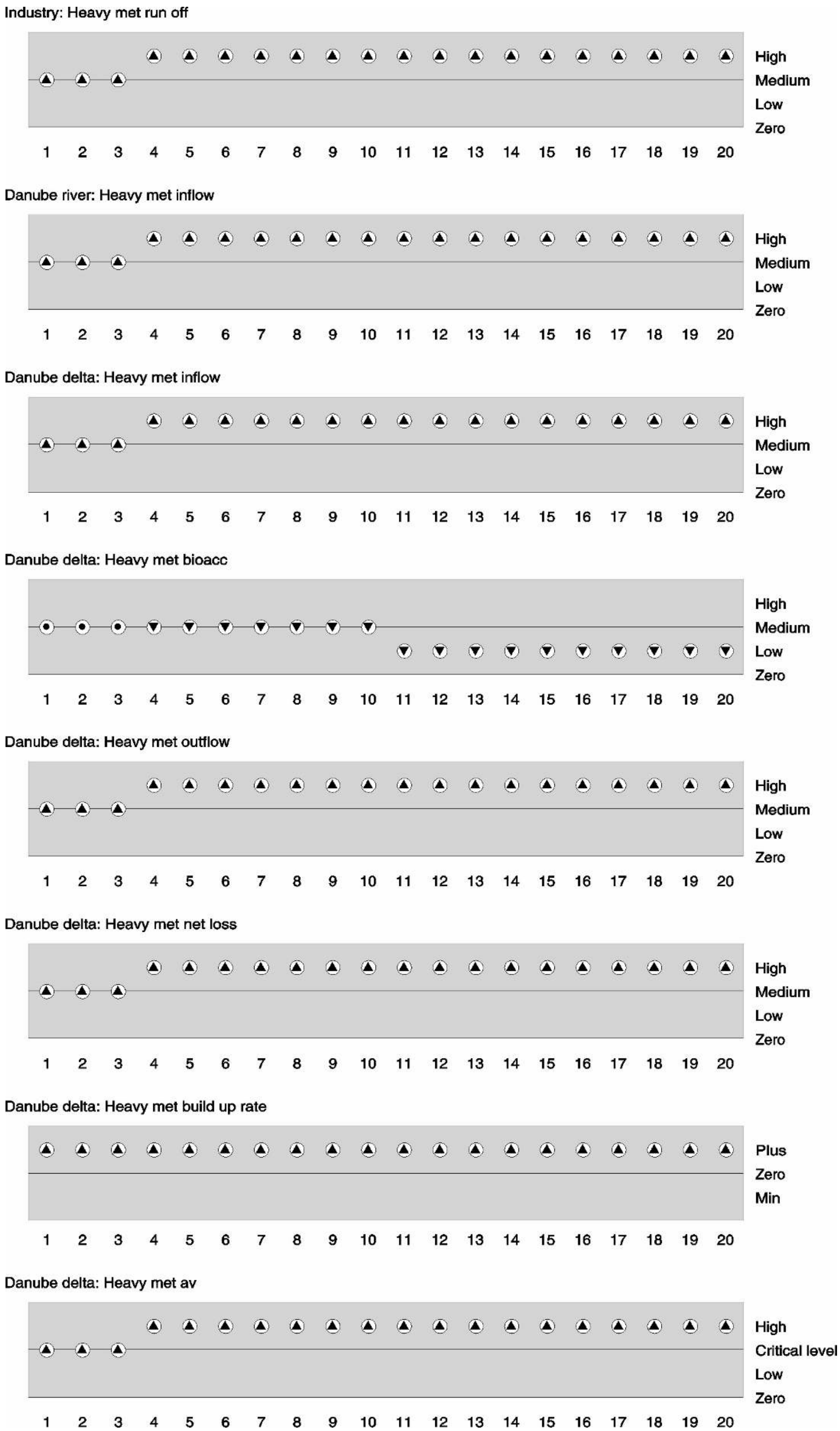


Figure 2.66 (II) Sce14 DD Water pollution and DD aquatic population biodiversity: State-graph value history

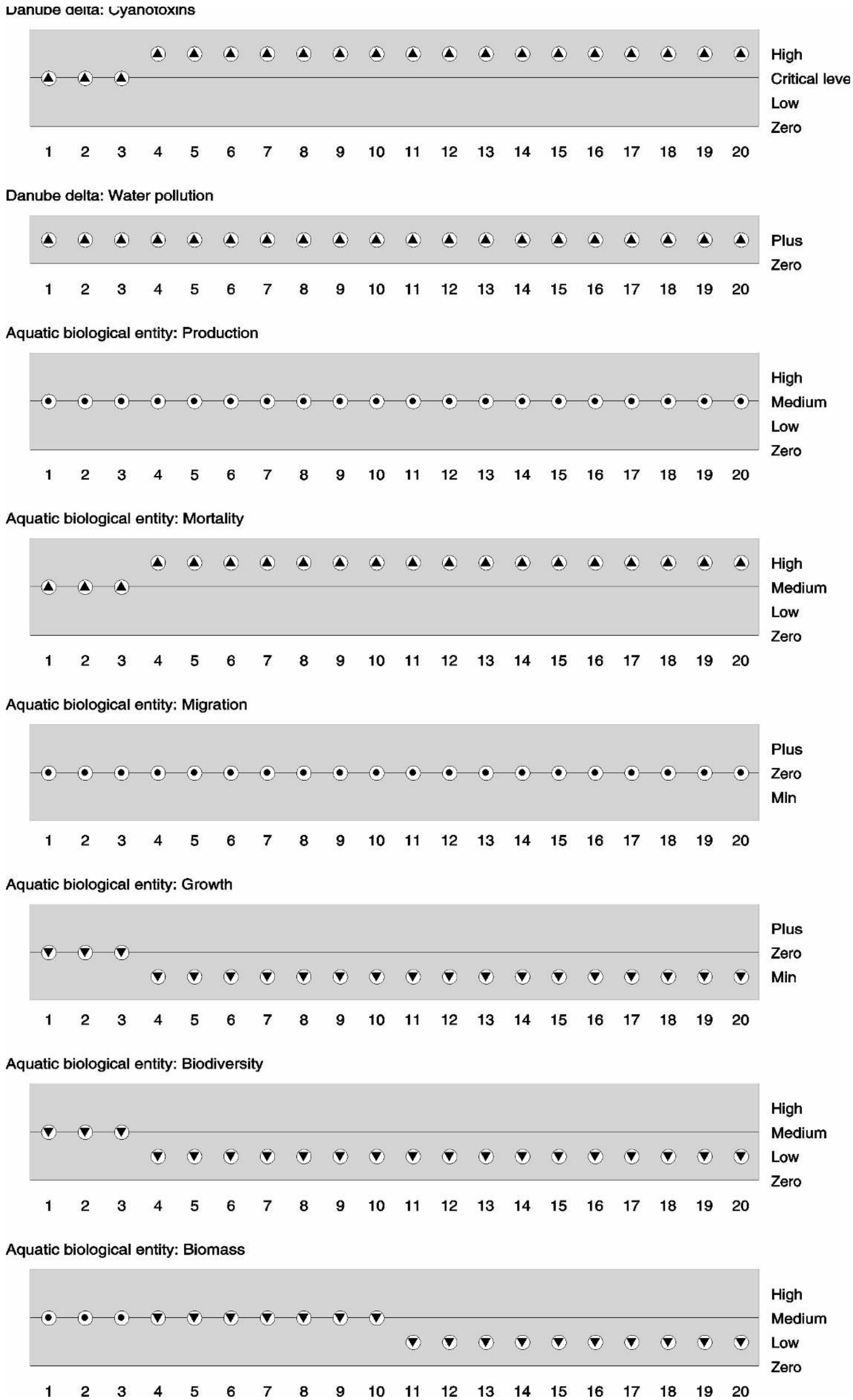


Figure 2.66 (III) Sce14 DD Water pollution and DD aquatic population biodiversity: State-graph Value history

These graphs show the behaviour of the water components (water pollutants) and aquatic biological populations with a general increase tendency of water pollutants (*Nutrients*, *Heavy metals*, and *Cyanotoxins*) *Aquatic biological entity*: *Mortality* and a general tendency decrease of *Aquatic biological entity*: *Growth*, *Biodiversity*, and *Biomass*, as result of the water pollution negative effect on any *Aquatic biological entity*.

2.22. Relevant paths of states

Relevant paths of states can be: [1→10→13→18→15] and [3→4→19→16→11→20], as selected (red coloured path of states) in the global state-graph (Figure 2.67 Sce14 DD Water pollution and DD aquatic population biodiversity: relevant paths of states).

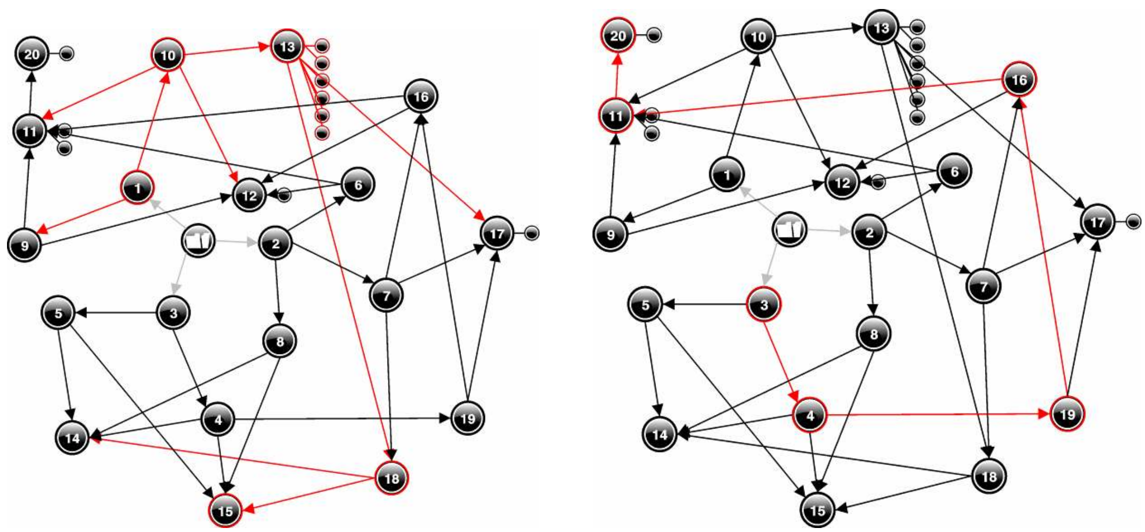


Figure 2.67 Sce14 DD Water pollution and DD aquatic population biodiversity relevant paths of states

2.22.1. Value history

For the two relevant paths of states, their value history diagrams are presented in Figure 2.68.

2.23. End states

The two relevant paths of states end with states 15 and 20, respectively. These states define the end of the process, for two extreme conditions of the system as result of the *Danube Delta*: *Nutrient net loss*, High, + and Zero, 0, respectively.

Within the water pollution process related to *Aquatic biological entity* behaviour, the *Aquatic biological entity*: *Biomass* never reaches the value Zero, because the *Growth* rate never reaches this value, as the assumption "*Growth on Migration only*" when Migration is assumed Zero/Steady, is not considered in this process.

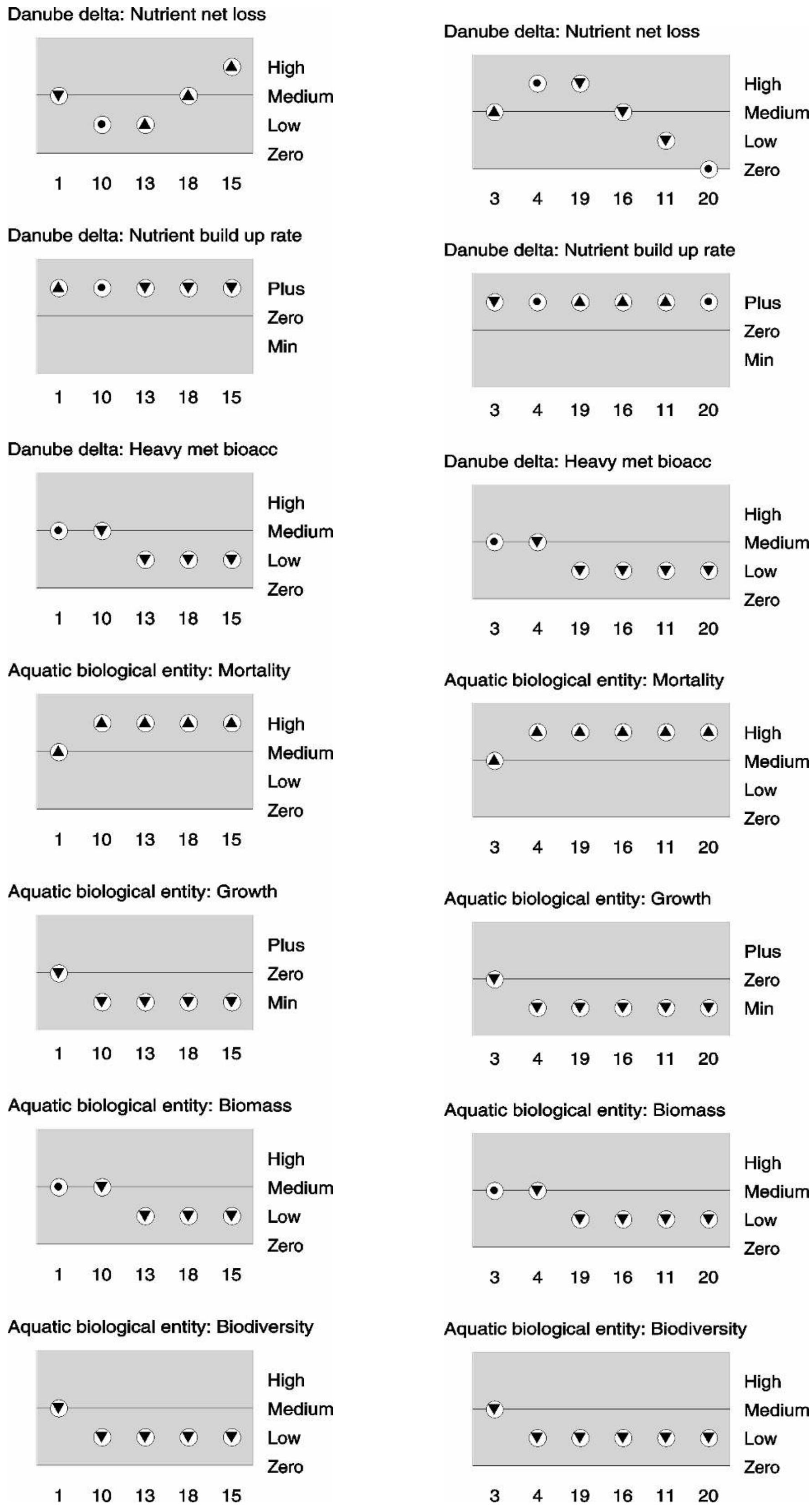


Figure 2.68 Sce14 DD Water pollution and DD aquatic population biodiversity: relevant path of states: Value history.

Scenarios concerning the *Human being* behaviour from the *Human health* point of view
State graph

2.24. Scenarios

There are constructed two Scenarios to model the Human being behaviour from the Human health point of view, directly influenced by the DDBR system water quality and indirectly by the fish quality, since people living in or around this area depend on water and fish as main life resources.
The Scenarios are:

Sce16 DD Human health influenced by DD water quality
Sce17 Human health influenced by DD Fish quality

These two Scenarios are constructed based on the following principles:

7. The modelled system's components are:
    a. *Human being*: *Human health*;
    b. *Danube Delta*: *Nutrient* and *Heavy metals*, as main *Water pollution process* components with negative influence on *Human being*: *Human health*, if there is a positive Water consumption rate by people.
    c. *Fish: Heavy metals bioaccumulation in fish* (muscle tissue) which have negative influence on *Human being*: *Human health*, if there is a positive Water consumption rate by people.
8. To reduce the simulation complexity, some Assumptions are introduced in Scenario construction, as follows:
    a. "*Assume nutrient consumption is zero and steady*" and *"Assume DD Human being water consumption positive*" (in Sce16);
    b. *"Assume Human being fish consumption positive*", "*Assume Migration is zero and steady*" and "*Assume Mortality is medium and steady*" (in Sce17);

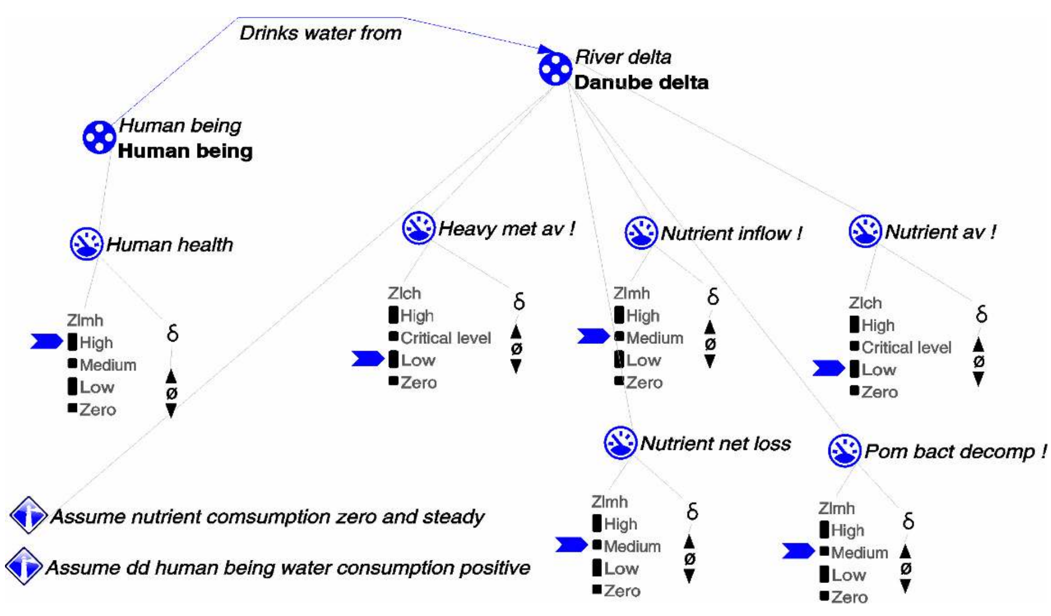


Figure 2.69 Sce16 DD Human health influenced by DD water quality Scenario.

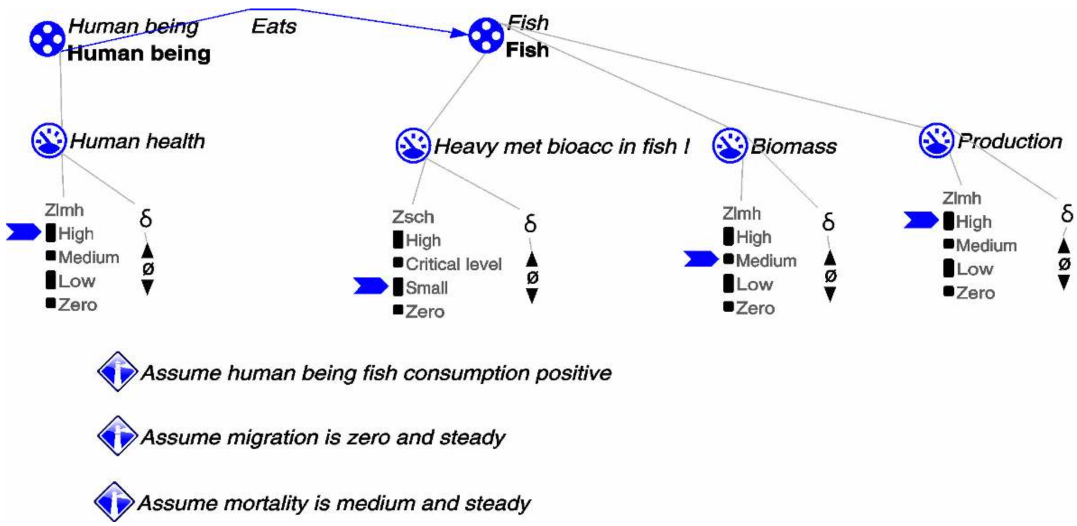


Figure 2.70 Sce17 Human health influenced by DD Fish quality Scenario.

From the two Scenarios constructed to model the Human being behaviour from the *Human health* point of view, simulation results are presented for one of them: Sce16 DD Human health influenced by DD water quality Scenario (Figure 2.69).

2.25. Begin states

2.25.1. Begin state definition

Begin states result from the initial quantity values as they are assigned in Scenario (Figure 2.69 Sce16 DD Human health influenced by DD water quality Scenario), as follows:

13. *Human being*: *Human health* High/None;
14. *River Delta*: *Heavy metals available* Low/Increase;
15. *River Delta*: *Nutrient inflow* Medium/Steady;
16. *River Delta*: *Nutrient Low*/Increase;
17. *River Delta*: *Nutrient net loss* Medium/None;
18. *River Delta*: *Pom (Particulate Organic matter) bacterial decomposition* Medium/ Increase;

2.25.2. State-graph

From the initial situation, 1 initial state results as shown in Figure 2.71.

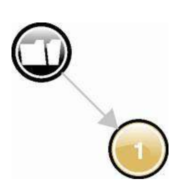


Figure 2.71 Sce16 initial state graph.

2.25.3. Equation history

The initial state equation history (Figure 2.72) shows that a possible start of the process can occur when: *Danube Delta*: *Nutrient inflow* > *Nutrient net loss*

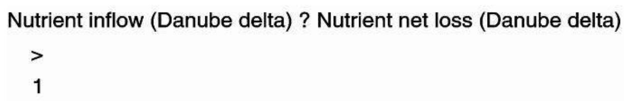


Figure 2.72 Sce16: Equation history of Initial state.

2.25.4. Value history graphs

The quantities and quantity value history of initial state is presented in Figure 2.73.
The values from this graph give information on the possible start of the process.
From initial quantities and their quantity values, as they are assigned in Scenario, the only initial state produced by simulation has the same values (by Magnitude, Derivative) and the quantity *Danube Delta*: *Nutrient build-up rate* is added getting the value Plus, -.

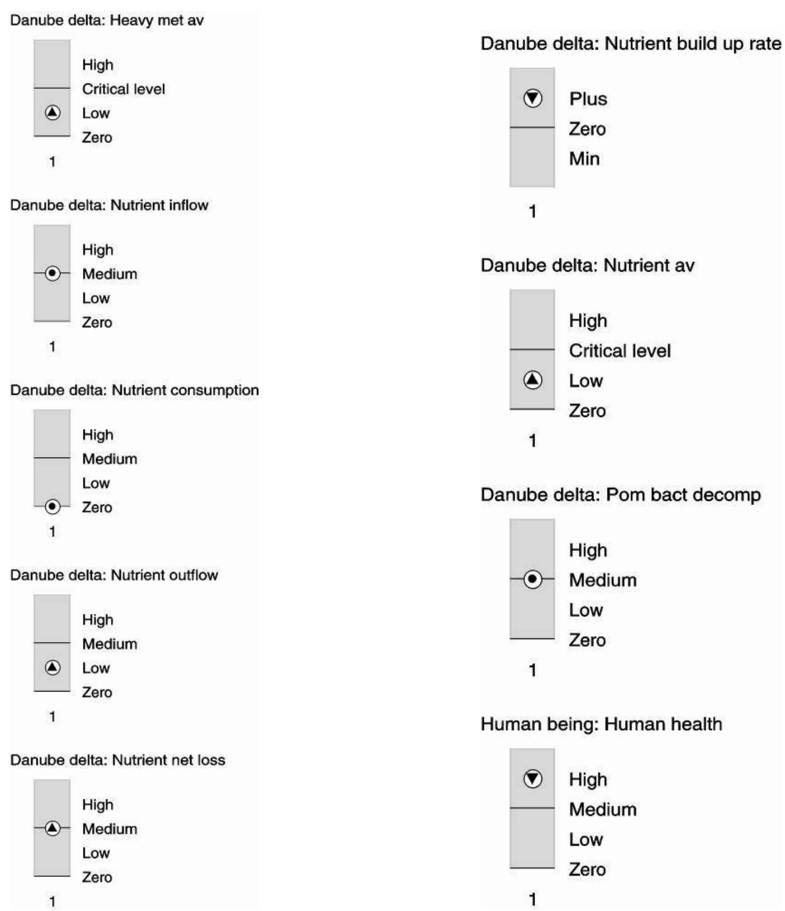


Figure 2.73 Sce16 Initial state's value history.

2.25.5. Dependency diagram

The initial state's dependency diagram is presented in Figure 2.74.

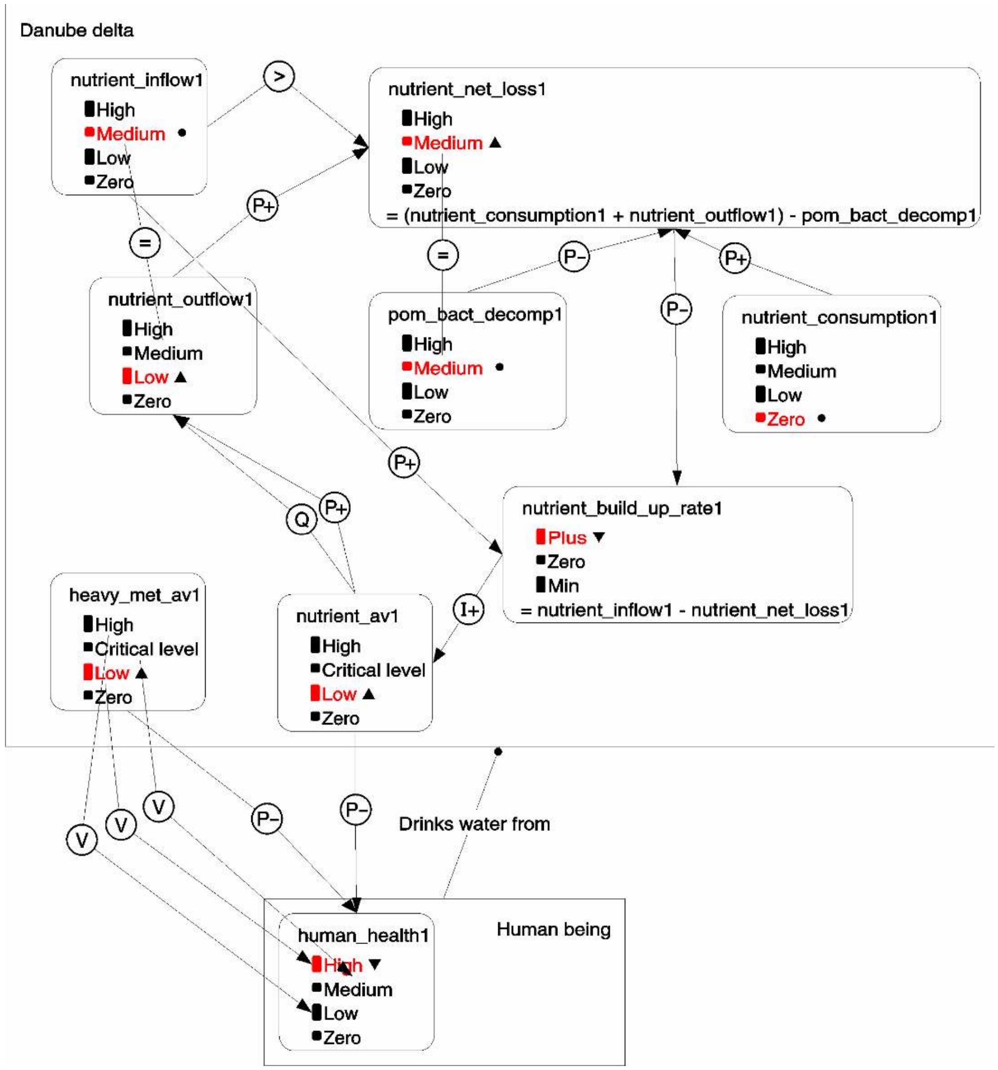


Figure 2.74 Sce16: Dependency diagram of Initial state 1.

This diagram (Figure 2. 74) provides information on structural and causality (Influence I, or Proportionality P), correspondence (Q, dQ) and In/equality (=, >, <) dependency relationships among the system's water pollutants (*Nutrient available* and *Heavy metals available*) and *Human being*: *Human health,* involved in process and their values that can start the process (as described in the above subsections).

2.25.6. Active Model fragments

The Figure 2.75 provides information on Model fragments used in the simulation process. Same MFs are active both in the only initial state1 and the only end-state 8 of the system.

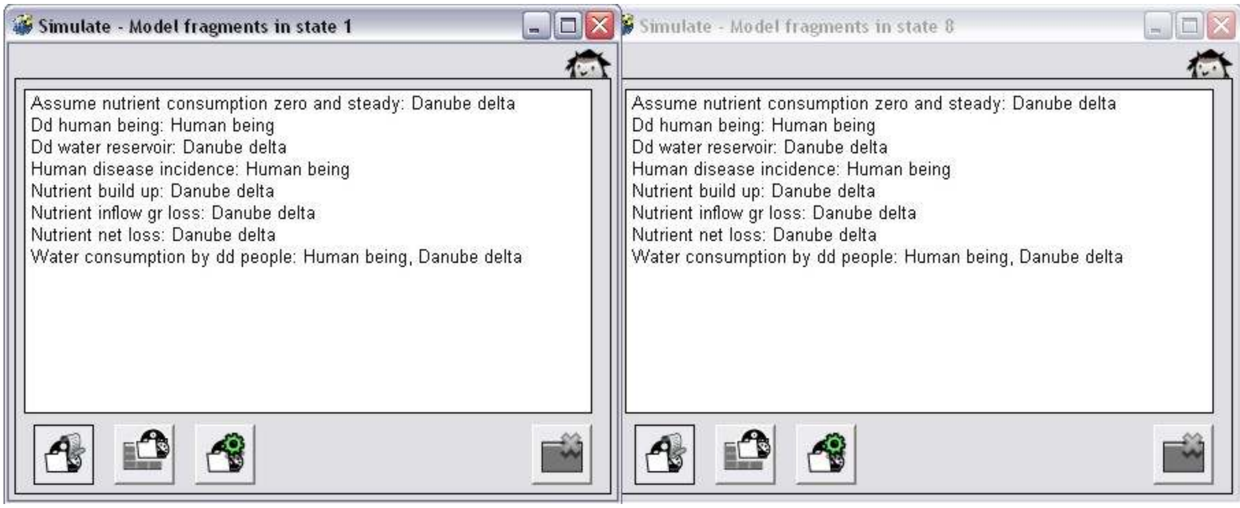


Figure 2.75 Sce16: Active Model fragments in Initial and state 1 and end-state 8.

2.26. Global State-graph

All states generated by full simulation, starting from initial state 1, are presented in Figure 2. 76. By full simulation of the initial state, a total number of 10 states are generated. One of them is end-states: 8.

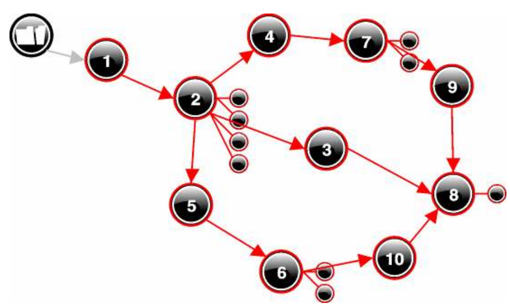


Figure 2.76 Sce16 DD Human health influenced by DD water quality global State-graph

I. 1 initial state

II. Full simulation states: 10 states.

III. 1 end states: 8.

2.26.1. Equation history

The global value history is presented in Figure 2.77. It shows that there is the same behaviour of the system, from one of the *Water pollution* component: (*Danube Delta*: *Nutrient inflow* > *Danube Delta*: *Nutrient net loss*) point of view, through states: 1÷10.

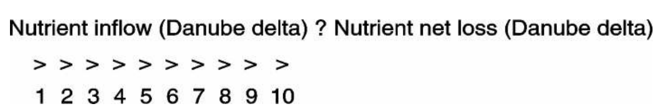


Figure 2.77 Sce16 DD Human health influenced by DD water quality global State-graph equation history

2.26.2. Value history graphs

The global state-graph value history is presented in Figures 2.78. These graphs show the behaviour of the *Human Being*: *Human health* depending on water pollution components (especially *Heavy metals available* in water) behaviour, with a general increase tendency of

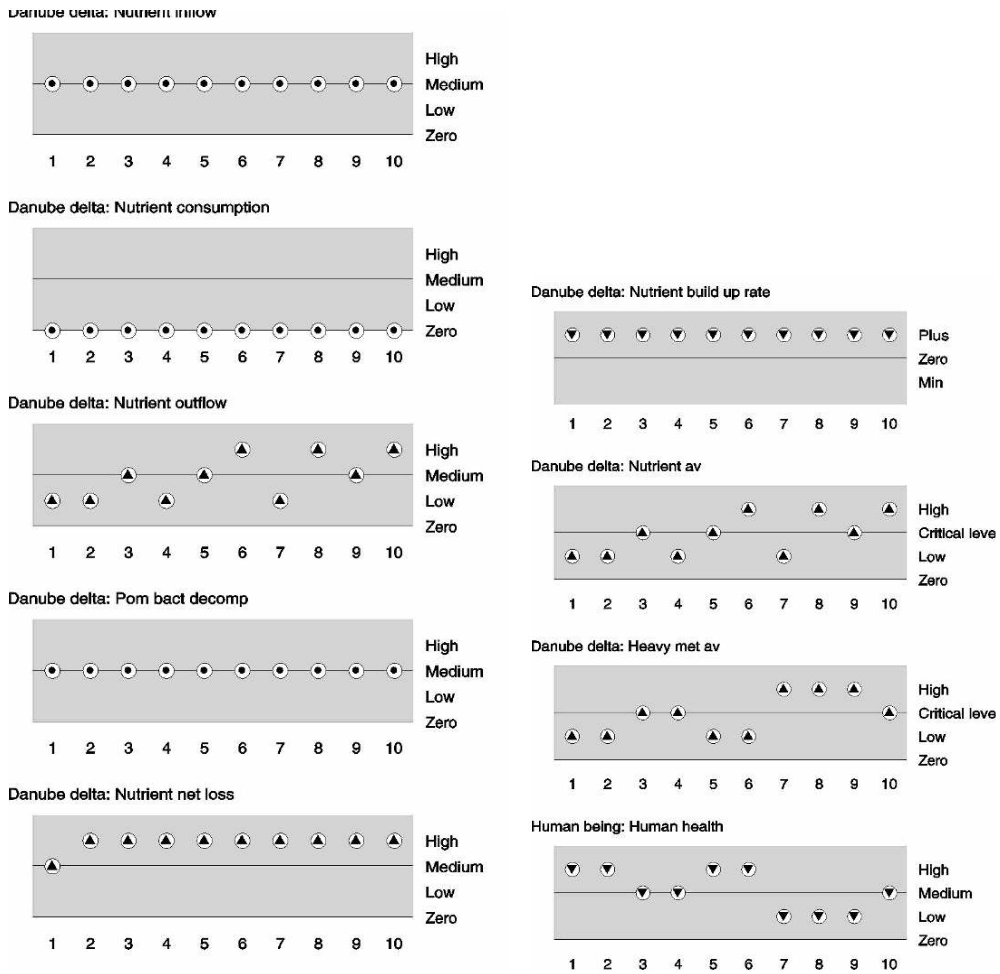


Figure 2.78 Sce16 DD Human health influenced by DD water quality global State-graph value history

water pollutants (*Nutrient available*, and *Heavy metals available*), from Low, -, to High, + and a general tendency decrease of *Human Being*: *Human health* from High, +, to Low, -, as result of the water pollution negative effect on *Human Being*: *Human health*.

2.27. Relevant path of states

One relevant path of states can be: [1→2→4→7→9→8], as selected (red coloured path of states) within the global state-graph (Figure 2.79 Sce16 DD Human health influenced by DD water quality global relevant paths of states).

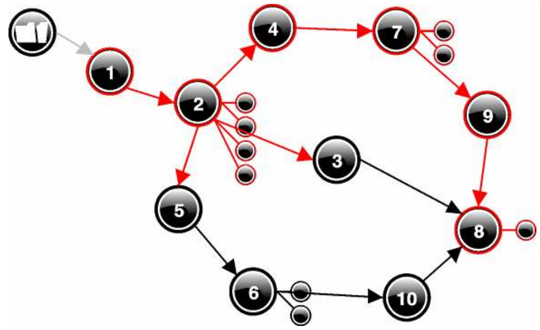


Figure 2.79 Sce16 DD Human health influenced by DD water quality global relevant paths of states

2.27.1. Value history

For the relevant path of states, their value history diagrams are presented in Figure 2.80.
The relevant path of states ends with state 8. This path of states shows one of the system possible behaviour. The end-state defines the end of the process, for the system extreme condition as it's determined by the:

1. *Danube Delta*: *Danube Delta*: *Heavy metals available*, High, + and *Nutrient available*, High, +;
2. *Human Being*: *Human health, Low, -*.

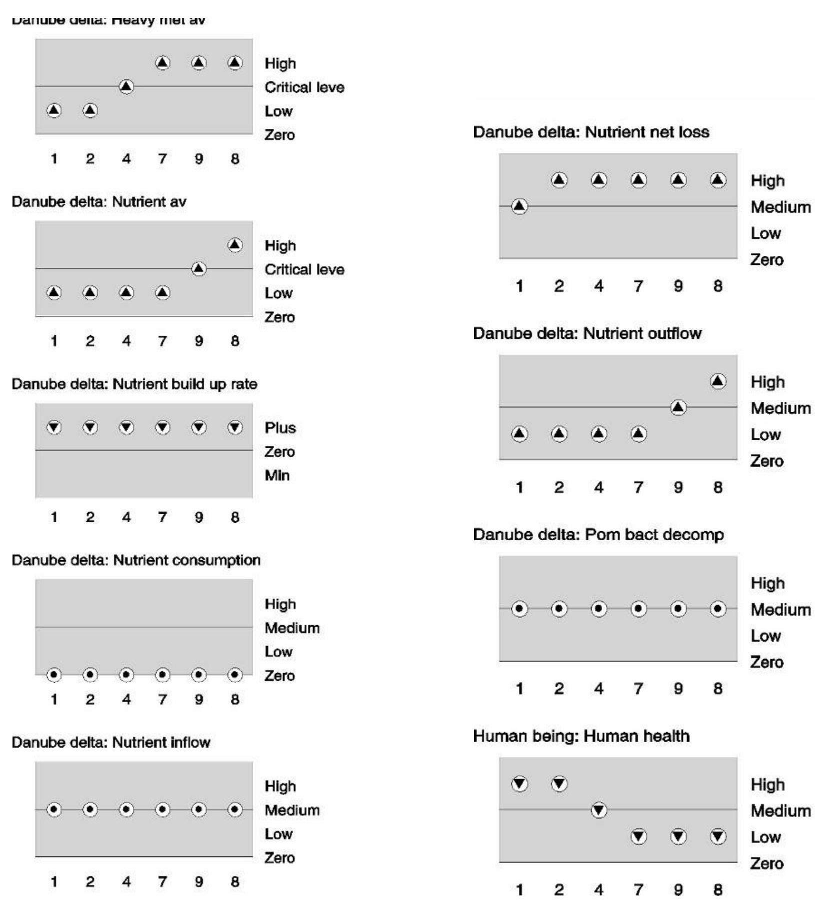


Figure 2.80 Sce16 DD Human health influenced by DD water quality global relevant paths of states: Value history

2.28. End-state

2.28.1. Dependency diagram

The end-state 8 dependency diagram is presented in Figure 2.81.

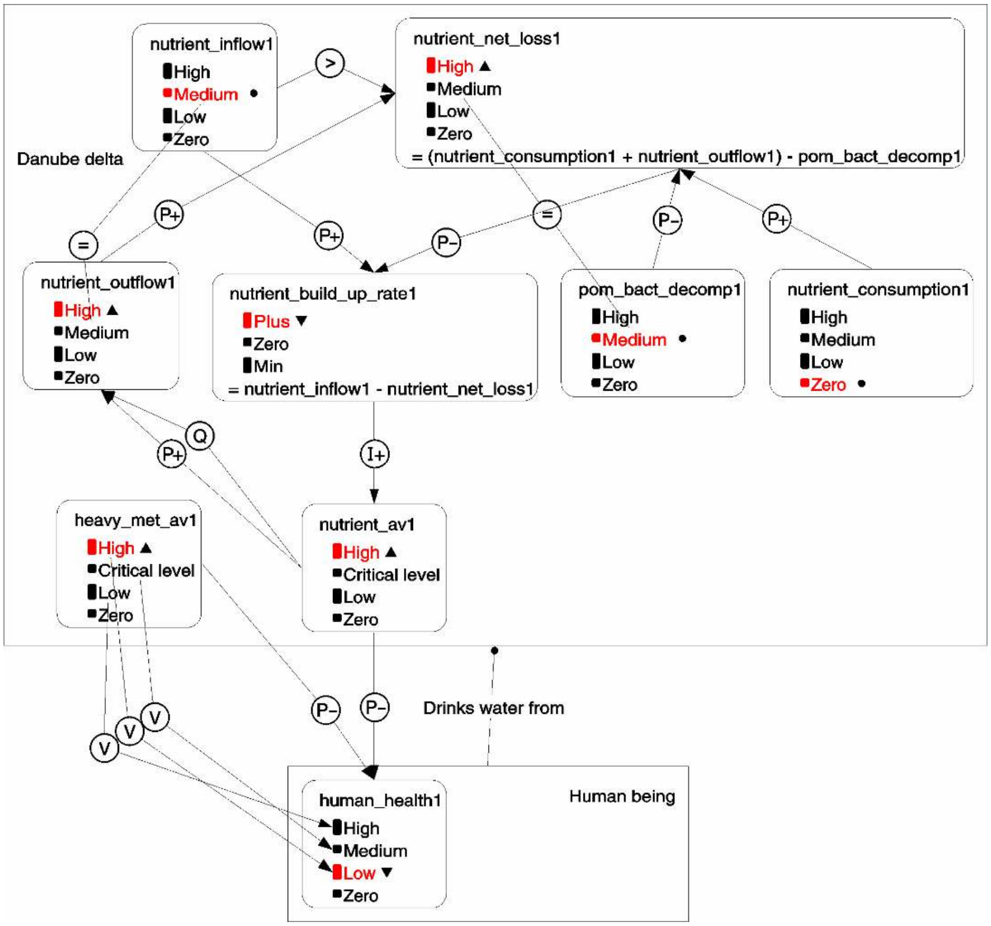


Figure 2.81 Sce16 DD Human health influenced by DD water quality - Dependency diagram of end-state 8

This diagram shows the system entities and their quantities extreme values for the only end-state 8. Within this system extreme condition the process can stop. The *Human being*: *Human health* Low, - is the lowest possible value this quantity can reach.

3. Summary tables

3.1. Scenario summary

Table 3.1 Scenario summary

Scenario name	Sce01 Diatoms growth process to low Nutrient inflow
Initial value	*1. Agriculture: Nutrient run-off*: Low/Constant *2. Diatoms / Blue green algae*: *Biomass*: Medium/None *3. River delta*: *Nutrient available*: Low/None; *Nutrient net loss*: Medium/None; *Temperature*: Zero/Increase, *Pom bacterial decomposition*: Medium/Steady.
Initial equation	*River delta*: *Nutrient available > Zero, Diatoms*: *Biomass > Zero*
Description	The aquatic *Plant* growth process is expecting to start when the *River delta*: *Nutrient available > Zero.*
Scenario name	Sce05 Blue-green algae growth process to high Nutrient inflow
Initial value	1. *Agriculture: Nutrient run-off*: High/Constant 2. *Diatoms / Blue green algae*: *Biomass*: Medium/None 3. *3. River delta*: *Nutrient available*: Low/None; *Nutrient net loss*: Medium/None; *Temperature*: Zero/Increase, *Pom bacterial decomposition*: Medium/Steady.
Initial equation	*River delta*: *Nutrient available > Zero, Blue-green algae*: *Biomass > Zero*
Description	The aquatic *Plant* growth process is expecting to start when the *River delta*: *Nutrient available > Zero.*
Scenario name	Sce07 Zooplankton and Fish growth process
Initial value	1. *Fish*: *Biomass*: Low/None, *Mortality*: Low/Constant; 2. *Zooplankton*: *Biomass*: Medium/None, the *Production*: Medium /Steady.
Initial equation	*Zooplankton*: *Biomass* >Zero; *Zooplankton*: *Production>Mortality*; *Fish*: *Biomass* >Zero; *Fish*: *Production>Mortality*
Description	This Model describe the *Fish* (Predator species) growth process based on *Zooplankton* (Prey species) as Fish main food resource in the framework of the Functional Feeding Group relationship
Scenario name	Sce11 FFG Diatoms Zooplankton and Fish
Initial value	1. *Diatoms (Prey species): Biomass,* Medium/None, *Production*, Medium/Steady 2. *Zooplankton (Predator/prey species)*: *Biomass*: Medium/None, the *Production*: Medium /Steady. 3. *Fish (Predator species)*: *Biomass*: Low/None, *Mortality*: Medium/Constant
Initial equation	*Diatoms*: *Biomass*>Zero; *Zooplankton*: *Biomass* >Zero; *Fish*: *Biomass* >Zero; *Diatoms*: *Production=Mortality; Zooplankton*: *Production>Mortality* *Fish*: *Production=Mortality*
Description	This Model describe the *Fish* (Predator species) growth process based on *Zooplankton* (Prey species) based on *Diatoms*: *Biomass* as *Zooplankton* main food resource in the framework of the Functional Feeding Group relationship
Scenario name	Sce14 DD Water pollution and DD aquatic population biodiversity
Initial value	19. *Agriculture*: *Nutrient run-off* High/Constant/None 20. *Industry: Heavy metals run-off* Medium/Increase 21. *River Delta*: *Nutrient available* Critical value/Increase 22. *River Delta*: *Nutrient net loss* Medium/None 23. *River Delta*: *Heavy metals available* Critical value/Increase 24. *River Delta*: *Heavy metals net loss* Medium/ Increase 25. *River Delta*: *Heavy metals bioaccumulation* Medium/ None

	26. *River Delta*: *Cyanotoxins* Critical value/Increase 27. *River Delta*: *Pom (Particulate Organic matter) bacterial decomposition* Medium/ Increase 28. *Aquatic population*: *Biomass* Medium/ None 29. *Aquatic population*: *Biodiversity* Medium/ None 30. *Aquatic population*: *Mortality* Medium/ None.
Initial equation	5. *Danube Delta*: *Heavy metals inflow* > *Heavy metals net loss* 6. *Danube Delta*: *Nutrient inflow* > *Nutrient net loss* 7. *Aquatic biological entity*: *Biomass* is > Zero 8. *Aquatic biological entity*: *Mortality* equals *Production*.
Description	The DDBR water pollution process, its negative effects and the ways it propagates to aquatic biotic component (*Aquatic biological entities*) are modelled.
Scenario name	Sce16 DD Human health influenced by DD water quality
Initial value	1. *Human being*: *Human health* High/None; 2. *River Delta*: *Heavy metals available* Low/Increase; 3. *River Delta*: *Nutrient inflow* Medium/Steady; 4. *River Delta*: *Nutrient Low*/Increase; 5. *River Delta*: *Nutrient net loss* Medium/None; 6. *River Delta*: *Pom (Particulate Organic matter) bacterial decomposition* Medium/ Increase;
Initial equation	*River Delta*: *Nutrient inflow* > *Nutrient net loss*
Description	The Danube Delta Biosphere Reserve water pollution process, its negative effects and the ways it propagates to Human being: Human health (If there is a positive *Human being*: *Water consumption*) are modelled.

3.2. Model fragment summary

Table 3.2 Model fragment summary

Model fragment name	1. *Assume migration is zero and steady* 2. *Assume mortality is medium and steady* 3. *Assume equal medium production and mortality* 4. *Assume nutrient consumption is Zero and steady* 5. *Assume production is medium and steady*.
Super type	Static
Description	*The five "Assumption" Model fragments, as named above, are constructed in order to reduce the simulation complexity. A pre-established value (both by its Magnitude and Derivative) associated to an Entity's quantity is assigned and an Assumption (label) is introduced as condition for this value never changes regardless of the other system components behaviour that can influence it.*
Model fragment name	*Danube River*
Super type	Static
Description	Introduces one of the most important quantities of the modelled system: *Danube River*: *Nutrient inflow*.
Model fragment name	*Western Black Sea*
Super type	Static
Description	Introduces one of the most important quantities of the modelled system: *Western Black Sea*: *Biodiversity*.
Model fragment name	*DD Human being*
Super type	Static

Description	Introduces one of the most important quantities of the modelled system: *Human being: Human health*.
Model fragment name	*Migration* and *Mortality*
Super type	Static
Description	2 MFs that introduce two quantities: *Migration* and *Mortality*, respectively, both associated to *Aquatic biological entity*.
Model fragment name	*Water reservoir*
Super type	Static, parent MF
Description	Introduces the *River Delta*: *Nutrient* forms.
Model fragment name	1. *Nutrient net loss* 2. *Heavy metals net loss.*
Super type	Static, children of *Water reservoir* parent MF.
Description	Introduce the details on *River Delta*: *Nutrient* / *Heavy metals* pollutants forms participating in water *Nutrient* / *Heavy metals net loss* content and dependences in terms of proportionalities, (in-) equality, and mathematical Calculus (Minus).
Model fragment name	*Biological entity*
Super type	Static, parent MF.
Description	Introduces the *Aquatic biological entity*: *Biomass.*
Model fragment name	1. *Population exists* 2. *Population none existing*
Super type	Static, children of *Biological entity* parent MF.
Description	Two MFs that introduce the two possible conditions for any *Aquatic population*. They specify one dependency in terms of (in-) equality: *Biomass* > Zero and *Biomass* = Zero, respectively.
Model fragment name	*Nutrient build- up*
Super type	Process, parent MF.
Description	Introduces the details on River Delta Nutrient construction rate and dependences in terms of direct influence, proportionalities, correspondence (in-) equality, and mathematical Calculus (Difference).
Model fragment name	1. *Nutrient inflow greater than loss* 2. *Nutrient inflow equals loss* 3. *Nutrient inflow smaller than loss.*
Super type	Process, children of *Nutrient build- up* parent MF.
Description	Introduce the (in-) equality dependency between *Nutrient inflow* and *Nutrient net loss*, as condition: >, -, and <, respectively.
Model fragment name	*River and river delta*
Super type	Process
Description	Specifies the details on water flow from River to River Delta, and introduces the Nutrient inflow quantity, configuration, and dependences in terms of proportionalities and correspondence.
Model fragment name	Aquatic Plant *Growth* process
Super type	Process, parent MF.
Description	Specifies the details concerning any *Aquatic population Growth* rate based on the difference between its *Production* and *Mortality* quantities.
Model fragment name	1. *Production greater than Mortality* 2. *Production equals Mortality* 3. *Production smaller than Mortality*.
Super type	Process, children of Aquatic Plant *Growth* process MF.
Description	Introduce the (in-) equality dependency between *Production* and *Mortality*, as condition: >, -, and <, respectively.
Model fragment name	*Plant Growth by Migration only*
Super type	Process
Description	Specifies the Growth of any Aquatic population based on its Migration

	only, in terms of direct influence, correspondence and equality.
Model fragment name	*Nutrient consumption by Plant*
Super type	Process
Description	Specifies the details concerning water Nutrient consumption by any aquatic Plant species, in terms of proportionality, correspondence, and (in-) equality dependency.
Model fragment name	*Production*
Super type	Process, parent MF.
Description	Introduce the quantity Production related to any Aquatic biological entity.
Model fragment name	*Production for Plant*
Super type	Process, children of *Production* MF.
Description	Specifies the details on any Plant Production based on Nutrient available in water, and introduces configuration, and dependences in terms of proportionalities and correspondence.
Model fragment name	*Aquatic macrophyte*
Super type	Process, parent MF.
Description	Specifies the details concerning one of the Plant (Aquaitc macrophyte) species Production depending on water Temperature, in terms of proportionality.
Model fragment name	1. *Aquatic macrophyte to high nutrient inflow* 2. *Aquatic macrophyte to low nutrient inflow* 3. *Aquatic macrophyte to medium nutrient inflow*.
Super type	Process, children of *Aquatic macrophyte* MF.
Description	Introduces the three possible conditions for the water Nutrient inflow content, in terms of this quantity value: low, medium and high, respectively, and the dependency of this Plant Production on water Temperature, in terms of correspondence between these two quantities values.
Model fragment name	*Phytoplankton growth*
Super type	Process, parent MF.
Description	Specifies the details concerning one of the Plant (Phytoplankton) species Production depending on water Temperature, in terms of proportionality.
Model fragment name	*6.1.1 Diatoms to low nutrient inflow* 6.1.2 *Diatoms to medium nutrient inflow* 6.1.3 *Diatoms to high nutrient inflow* 6.1.4 *Blue-green algae to medium nutrient inflow* 6.1.5 *Blue-green algae to high nutrient inflow*.
Super type	Process, children of *Phytoplankton growth* MF.
Description	Introduces the three possible conditions for the water Nutrient inflow content, in terms of this quantity value: low, medium and high, respectively, and the dependency of these Plants (Diatoms and Phytoplankton species, respectively) Production on water Temperature, in terms of correspondence between these two quantities values.
Model fragment name	*Blue-green algae and Cyanotoxins production*.
Super type	Process
Description	Specifies the details on Cyanotoxins production process, based on dead matter of Blue-green algae Plant species Particulate Organic Matter bacterial decomposition process, by configuration and dependences in terms of proportionalities, correspondence, and (in-) equality.
Model fragment name	*Zooplankton growth process*
Super type	Process
Description	Specifies the details on Zooplankton (Aquatic animal species) growth

	process, based on Diatoms biomass, by configuration, and dependences in terms of proportionalities, correspondence, and (in-) equality.
Model fragment name	*Fish growth process*
Super type	Process
Description	Specifies the details on Fish growth process, based on Diatoms biomass, by configuration and dependences in terms of proportionalities, correspondence, and (in-) equality.
Model fragment name	*Bird growth process*
Super type	Process
Description	Specifies the details on Bird growth process, based on Fish biomass, by configuration and dependences in terms of proportionalities, correspondence, and (in-) equality.
Model fragment name	*Macroinvertebrate growth process*
Super type	Process
Description	Specifies the details on Macroinvertebrate growth process, based on Aquatic macrophyte biomass, by configuration and dependences in terms of proportionalities, correspondence, and (in-) equality.
Model fragment name	*Heavy metals build-up*
Super type	Process
Description	Introduces the details on River Delta Heavy metals construction rate and dependences in terms of direct influence, proportionalities, correspondence (in-) equality, and mathematical Calculus (Difference).
Model fragment name	1. *Heavy metals inflow greater than loss* 2. *Heavy metals inflow equals loss* 3. *Heavy metals inflow smaller than loss.*
Super type	Process, children of *Heavy metals build-up* parent MF.
Description	Introduce the (in-) equality dependency between *Heavy metals inflow* and *Heavy metals net loss*, as condition: >, -, and <, respectively.
Model fragment name	*Heavy metals bioaccumulation in aquatic organism bodies*
Super type	Process
Description	Specifies the details concerning water Heavy metals bioaccumulation (similar with Nutrient consumption) in any aquatic biological entity, in terms of proportionality, correspondence, and (in-) equality dependency.
Model fragment name	*DD Water pollution process*
Super type	Process, parent mF.
Description	Specifies the details on River Delta Water pollution construction rate and dependences in terms of proportionalities and mathematical Calculus (Sum).
Model fragment name	*DD Water pollution and dd aquatic population biodiversity*
Super type	Process
Description	Specifies the details on DD aquatic population biodiversity under direct influence on DD Water pollution positive rate and dependences in terms of influence, proportionalities and correspondence.
Model fragment name	*DD Water pollution and Black Sea biodiversity*
Super type	Process
Description	Specifies the details on Western Black Sea aquatic population biodiversity under direct influence on DD Water pollution positive rate and dependences in terms of influence.
Model fragment name	*Human being health*
Super type	Process, parent MF.
Description	This is an imported MF to play the parent MF role for the two children MFs.
Model fragment name	*Human being health influenced by water consumption*

Super type	Process
Description	Specifies the details on DD Human being health influenced negatively by the DD water pollutants, if there is a positive water pollution with Nutrients and Heavy metals and a positive water consumption by people. Dependences are specified in terms of proportionalities and correspondence. It contains, as condition, the assumption: Assume dd human being water consumption positive.
Model fragment name	*Human being health influenced by fish consumption*
Super type	Process
Description	Specifies the details on Human being health influenced negatively by the DD Fish if there is a fish pollution with Heavy metals bioaccumulated in Fish muscle tissue and a positive fish consumption by people. Dependences are specified in terms of proportionalities and correspondence. It contains, as condition, the assumption: Assume human being fish consumption positive.
Model fragment name	1. *Nutrient run-off by Agriculture* 2. *Heavy metals run-off from Industry*
Super type	Agent
Description	Specifies the details concerning the two modelled system's external influences: Nutrient run-off by Agriculture and Heavy metals run-off from Industry, respectively on the River Nutrient inflow and Heavy metals inflow content, respectively. There are specified dependences in terms of proportionalities and correspondence.

3.3. Simulation summary

To model the Danube Delta Biosphere Reserve aquatic ecosystem behaviour a number of 17 Scenarios have been constructed.
To present the detailed description of Scenario simulation results some of the 17 Scenarios have been selected, as representative for each particular group of Scenarios, as shown in Simulation results chapter and in Table 3.1 (Summary table chapter). For the same selected Scenarios, the Simulation summary is presented in Table 3.3.

Table 3.3 Simulation summary

Scenario name	Sce01 Diatoms growth process to low Nutrient inflow
Full simulation	44 states
Begin state(s)	[1, 2, 3, 4]
End state(s)	[25], [42]
Behaviour – Relevant path of states	[1→11→14→33→39→43→44→42].
Behaviour description	This behaviour represents the expected behaviour of the plant (Diatoms species) with biomass decreasing as result of water Nutrient inflow content constantly Low, and getting Zero, when its growth is Zero (within the particular situation when Growth is based on Migration only and Migration is assumed Zero/Steady).
Scenario name	Sce05 Blue-green algae growth process to high Nutrient inflow
Full simulation	33 states
Begin state(s)	[1, 2, 3, 4]
End state(s)	[5], [21], [31].
Behaviour - Relevant path of states	[1→11→15→23→24→28→32→33→31].
Behaviour description	This behaviour represents the expected behaviour of the plant (Blue-green algae species) with biomass decreasing/increasing as result of its Growth negative/positive rate, in water Nutrient inflow content constantly High condition.

Scenario name	Sce07 Zooplankton and Fish growth process
Full simulation	20 states
Begin state(s)	[1]
End state(s)	[12], [20].
Behaviour - Relevant path of states	[1→2→3→4→5→6→7→8→10→11→14→15].
Behaviour description	The behaviour shows an increase/decrease of the two aquatic animal species (*Fish* and *Zooplankton*) biomass in a continuously sinusoidal change of values, which shows that there is a continuous Growth process of one population (Fish, as predator species) based on the other population (Zooplankton, as prey species), respectively, in the framework of the Functional Feeding Group relationship between them.
Scenario name	Sce11 FFG Diatoms Zooplankton and Fish
Full simulation	56 states
Begin state(s)	[1]
End state(s)	[14], [34], [35].
Behaviour - Relevant path of states	[1→2→3→4→5→9→12→17→22→28→33→38→43→2].
Behaviour description	The behaviour shows a continuous increase/decrease of the three aquatic populations (Fish, Zooplankton, and Diatoms), which behave as predator (Fish), prey (Diatoms), and both predator and prey (Zooplankton) in the framework of the functional feeding Group relationship among them. The behaviour shows there is an endless process, so none of the three population biomass reaches zero value.
Scenario name	Sce14 DD Water pollution and DD aquatic population biodiversity
Full simulation	20 states
Begin state(s)	[1, 2, 3]
End state(s)	[12], [14], [15], [17], [20].
Behaviour - Relevant path of states	[1→10→13→18→15].
Behaviour description	The Aquatic biological entity biomass and biodiversity, implicitly, has the general tendency to decrease as result of water pollution positive rate and positive influence on biological entity mortality, but never reaches the value Zero, because its growth rate never reaches this value.
Scenario name	Sce16 DD Human health influenced by DD water quality
Full simulation	10 states
Begin state(s)	[1]
End state(s)	[8]
Behaviour - Relevant path of states	[1→2→4→7→9→8].
Behaviour description	The behaviour shows a continuously decrease of human health as result of a continuous increase of water pollution component (Nutrient and Heavy metals) content.

Conclusions

This deliverable contains a detailed description of the **Danube Delta Biosphere Reserve case study Qualitative Reasoning Model Documentation**. It emphasizes the main causes and their effects that challenge achievement of Sustainable Development within the DDBR.

The Qualitative Reasoning concept is implemented as one of the two tools developed within the NaturNet-Redime project, in order to assist the Sustainable Development Strategy of any social, economic, or environmental system. Qualitative Reasoning (QR) is of great importance for developing, strengthening and further improving education and training on topics dealing with systems and their behaviours (Bert Bredeweg, 2005).

To model qualitatively the DDBR aquatic ecosystem components behaviour, a number of 17 Scenarios and a library of 57 Fragments have been constructed (Figure 1.0 Garp3 software main page and Figure 1.6 The DDBR system QR model Scenarios names). They relate to the main system's processes involved in aquatic ecosystem populations (flora and fauna species) growth and Human population (living in or around this area) health. Their structure and the Scenarios simulation results, as detailed description, are presented in this deliverable.

The DDBR Qualitative Reasoning Model Fragments emphasize the causality conditions which have been generating loss of DDBR biodiversity, in order to delimit those objectives for a sustainable use of natural resources, and a Sustainable Development Strategy addressing the aquatic ecosystems. Conservation and protection of DDBR biodiversity (both as natural resource use and as conservative concern) is one of the main objectives in achieving the Sustainable Development Strategy for this area. These must be based on the best current understanding of the phenomena which occur within and beyond the delta, including the whole basin of the Danube River and the Western Black Sea coastal zones.

Knowledge about the aquatic ecosystems behaviour within DDBR system, as it is presented in the DDBR QR Model and within this model documentation (D6.2.2), serves for making decisions for sustainable use of natural resources and protection of the natural heritage as well. This is a requirement in achieving the environmental and socio-economic sustainable development within the Danube Delta Biosphere Reserve system.

The complete **documentation** for learning about relevant concepts of sustainability of the DDBR system also includes the D6.2.1 "*Textual description of DDBR case study*" (Cioaca et all, 2006), which informs about the modelled system's features and Stakeholders issues within DDBR, and the milestone M6.4 which contains detailed description of system's structure, entities, quantities and the initial versions of DDBR QR model[5] scenarios, MFs, and simulation results.

The DDBR QR Models (final and initial versions .hgp files) and the models documentation are materials of educational purpose on SD. Also, they are learning materials which will become input for three other activities within NNR: (a) collaborative modelling approach for T6.5, and T6.6; (b) Integrated Library of Model Fragments about Sustainable Development (T6.7); and (c) Curricula for learning about Sustainable Development (T6.10).

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[5] Initial versions of DDBR QR Models (.hgp files) and their scenarios, MFs, and Simulation results description will be presented in a separate volume named as "DDBR QR Models: READ ME"

collaborative work. I am grateful and want to thank all colleagues[6] for their interest and contribution to this project. Many thanks especially to Bert Bredeweg and Paulo Salles for providing me their significant support both in teaching about QR and constructing the Danube Delta Biosphere Reserve QR Model and to Tim Nuttle for his valuable revision of this report.

References

1. Bert Bredeweg, Anders Bouwer and Jochem Liem, University of Amsterdam Paulo Salles, University of Brasil, D6.1 Framework for conceptual QR description of case studies. www.naturnet.org
2. B. Bredeweg*, P. Salles, A. Bouwer, J. Liem, T. Nuttle, E. Cioaca, et al (2006): Towards a Structured Approach to Qualitative Modelling. ISEI5 conference *PROCEEDINGS*, ”Novel Computational Techniques for Improved Management, Understanding and Forecasting of Complex Ecological Data”, December 4 – 6, 2006 • Santa Barbara, CA, USA (in press), http://www.isei5-conference.elsevier.com/.
3. Cioaca, E., Nuttle, T., Bredeweg, B. (2006): The Danube Delta Biosphere Reserve: a Case Study for Qualitative Modeling of Sustainable Development. *QR-06 20th International Workshop on Qualitative Reasoning PROCEEDINGS. pp.151-156. July 10-12, 2006. Dartmouth College, Hanover, New Hampshire, USA*. http://www.cs.dartmouth.edu/~qr06/papers/cioaca-nuttle-bredeweg-qr06.pdf.
4. Cioaca, E., Covaliov, S., Tudor, M., Torok, L., Ibram, O. (2006): D6.2.1 Textual description of the Danube Delta Biosphere Reserve case study focusing on basic biological, physical, and chemical processes related to the environment http://www.naturnet.org/admin/deliverables.php
5. Cioaca (E), 2001 – Morphohydrographic evolution of the Danube Delta Biosphere Reserve zones subject to the ecological reconstruction process. *Scientific annals of DDNI*, pp. 36-46.
6. Nuttle, T., Salles, P., Uzunov, Y., Cioaca, E. et all (2006): Progress in developing cognitive models of sustainability: case studies from European and Brazilian river basins. NaturNet-Redime NEWSLETTER No. 2 January 2006, pp12-15. http://www.naturnet.org/include/content/newsletter/newsletter02.pdf.
7. Salles, P. & Bredeweg, B. (1997) Building Qualitative Models in Ecology. In Ironi, L. (ed.) *Proceedings of the 11th. International Workshop on Qualitative Reasoning (QR’97)*. Instituto di Analisi Numerica C.N.R., Pubblicazioni no. 1036 , Pavia, Italy.
8. Tim Nuttle, Bert Bredeweg, Paulo Salles (2006): D6.8 Guidelines for Sustainable Development Curriculum, . www.naturnet.org.
9. ADRIAANSE (M.), NIEDERLANDER, (H.A.G.), STORTELDER, (P.B.M.), 1995 Monitoring Water Quality in the Future, vol. 1: Chemical Monitoring, The Netherlands, 100 p.
10. BEST (S. D.), 1989 - Ecological Monitoring Best Practice in the Environment Agency. M. Sc. Thesis, University of Wales, Aberystwyth, UK.
11. CHORLEY (R.J.), 1973 – Introduction to fluvial processes. 211p.Edit. Richard J Chorley, Methuen & Co Ltd, Great Britain.
12. “daNUbs” FP6 project: Nutrient Management in the Danube Basin and its Impact on the Black Sea (http://danubs.tuwien.ac.at).
13. TIMMS (R.M.), MOSS (B.), 1984 - Prevention of growth of potentially dense phytoplankton populations by zooplankton grazing, in the presence of zooplanktivorous fish, in a shallow wetland ecosystem. *Limnology and Oceanography*, vol. 29, pp. 472-486.
14. SCHEFFER (M.), 1998 - Ecology of shallow lakes. *Population and community biology*, 22nd ed.,Chapman & Hall, Lelystad, the Netherlands.
15. OOSTEMBERG W., BUIJSE (A.D.), COOPS (H.), IBELINGS (B.W.), MENTING (G. A. M.), STARAS 2000 - Ecological gradients in the Danube Delta Lakes. Present state and man-induced changes. pp. 51-160. Edited by the Institute for Inland Water Management and Waste Water Treatment (RIZA, Netherlands) and the DDNI (Tulcea, Romania).

[6] Silviu Covaliov, Liliana Torok, Mihaela Tudor, and Orhan Ibram (Danube Delta National Institute, Tulcea, Romania), Bert Bredeweg, Jochem Liem, Anders Bouwer (University of Amsterdam, Informatics Institute, Human Computer Studies Laboratory), Paulo Salles (University of Brasil), Tim Nuttle (University of Jena, Germany).

16. GASTESCU, P., Breier, Ariadna, 1980, Present changes in the Danube Delta morphohydrography, RRGGG-Géogr., 24.
17. OTEL at all, 1991-1995, Red List of the Danube Delta Biosphere Reserve plants and animal species, DDNI Scientific Annals.
18. Vannote, R.L., Minshall G.W., Cummins, K.W., Sedell, J.R. & Cushing, C.E. (1980). The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37: 130-137.
19. Otchere, F. A. (2003). "Heavy metals concentrations and burden in the bivalves (*Anadara* (*Senilia*) senilis, *Crassostea tulipa* and *Perna perna*) from lagoons in Ghana: Model to describe mechanism of accumulation/excretion." African Journal of Biotechnology Vol. 2(9)(1684-5315): 280-287.
20. Premazzi G. Chiaudani G. (1992). EUR 14563 - Ecological Quality of Surface Water.Quality assessment schemes for European Community lakes, Environment Institute University of Milan.
21. Ibram Orhan, Cristina David, Liliana Cojocaru, 2001. Nutrients and heavy metals dynamic in the Danube Delta lakes.
22. Scheffer, M. (1998). Ecology of shallow lakes. Lelystad, CHAPMAN&HALL.
23. Wachs B., 2000."Heavy metal content in Danubian fish."Arch. Hydrobiol. Suppl.115/4: 533-566.

Annex 1.

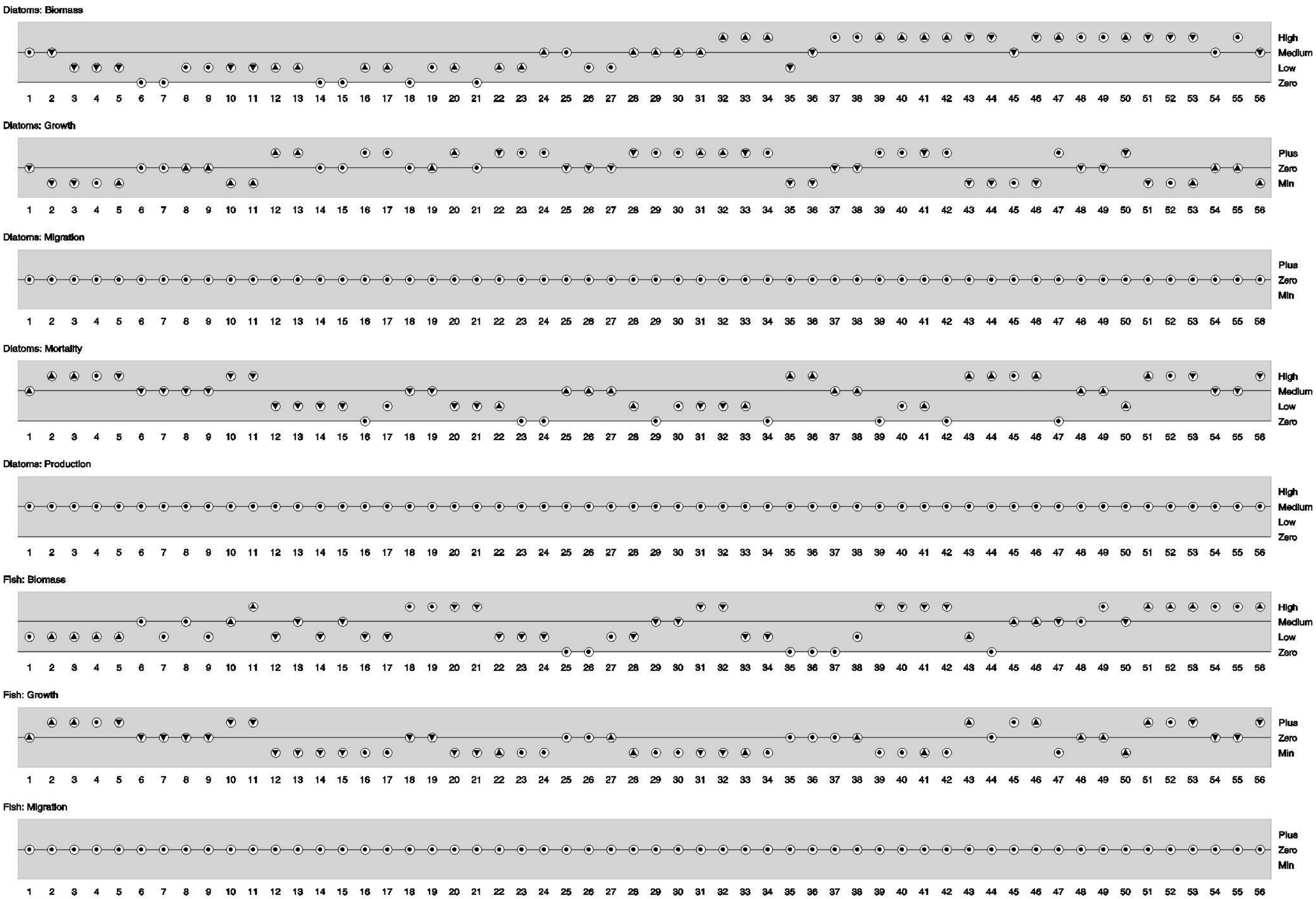
Diatoms: Biomass
High
Medium
Low
Zero
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Diatoms: Growth
Plus
Zero
Min
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Diatoms: Migration
Plus
Zero
Min
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Diatoms: Mortality
High
Medium
Low
Zero
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Diatoms: Production
High
Medium
Low
Zero
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Fish: Biomass
High
Medium
Low
Zero
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Fish: Growth
Plus
Zero
Min
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
Fish: Migration
Plus
Zero
Min
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Figure 2.47 Sce11 FFG Diatoms Zooplankton and Fish - Global state-graph: Value history

Biomass (Diatoms) ? Zero

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Biomass (Fish) ? Zero

> = = > > > > > > > > = = = > > > > > > = > > > > > > > > > > > >
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Biomass (Zooplankton) ? Zero

> > > > > > > > > > > > > > > = > > > > > > = = > > > > = > > > > = > > > > = > > = > > > > = > > > > > > > > >
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Migration (Diatoms) ? Growth (Diatoms)

= = = = = =
6 7 14 15 18 21

Migration (Fish) ? Growth (Fish)

= = = = = =
25 26 35 36 37 44

Migration (Zooplankton) ? Growth (Zooplankton)

= = = = = = = =
16 23 24 29 34 39 42 47

Production (Diatoms) ? Mortality (Diatoms)

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Production (Fish) ? Mortality (Fish)

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Production (Zooplankton) ? Mortality (Zooplankton)

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Figure 2.48 Sce11 FFG Diatoms Zooplankton and Fish - Global state-graph: Equation history